

2023 Conference on Systems Engineering Research

Introducing Technical Debt link to Leading Indicators in Test and evaluation phase of Systems Engineering – a thought experiment

Zakaria Ouzzif^a, Shamsnaz Bhada^b

^aWorcester Polytechnic Institute, 100 Institute Rd, Worcester, MA 01609, USA

^bWorcester Polytechnic Institute, 100 Institute Rd, Worcester, MA 01609, USA

Abstract

The term technical debt (TD) is no longer limited to software engineering but can be applied to the full product development lifecycle. Technical debt is particularly relevant to systems engineers because it impacts product development as well as program execution, resulting in lower productivity and increased risk. Although TD has its benefits, Leading Indicators have traditionally been used in Systems engineering to help prevent surprises during system development by providing timely information about potential problems, improve cost estimating by providing more accurate information about the system under development, and provide information about which activities are most likely to impact the schedule.

The use of leading indicators (LI) supports the effective management of systems engineering by enabling predictions of expected project performance and potential future states. Moreover, leading indicators aid leadership in delivering value to customers and end users, while facilitating interventions and actions to avoid rework and wasted effort¹.

This paper examines how different technical debt types can be linked to leading indicators in systems engineering. It also provides a simple introduction of technical debt to systems engineers and technical program managers presenting leading indicators in systems engineering as an established methodology with relevant metrics.

© 2023 The Authors.

Keywords: Technical Debt; Leading Indicators; Systems Engineering.

Introduction

The implementation of technical debt management processes in organizations concerned with software engineering and development has been shown to result in economic benefits [2] such as predicting cost of future bids and reducing negative impact on cost and schedule in current efforts. However, literature is lacking regarding how systems engineering professionals and program managers can benefit from effectively recognizing, tracking, and managing technical debt in systems engineering and management.

® 2023 The Authors.

Technical debt is often seen as a necessary evil in software engineering. It is a way to trade short-term gains for long-term benefits. By taking on technical debt, a company can get a product to market faster and start generating revenue sooner. The downside is that it will eventually need to be paid back, with interest.

There are several advantages to taking on technical debt. First, it can help a company to get a product to market faster. This can be a major advantage, especially in industries where time to market is critical. Second, it can help a company to generate revenue sooner. This is important because it can provide the resources needed to invest in further development and growth. Third, it can improve a company's competitive position. In a market where everyday counts, getting a product to market even a few days sooner can be the difference between success and failure. Fourth, technical debt can improve a company's cash flow, while meeting all critical requirements. This is because the up-front investment required to pay back the debt is typically less than the revenue generated by the product. Systems engineers use leading indicators and process models to track technical debt to better understand and manage the risk associated with it.

By understanding the relationship between leading indicators and technical debt management, systems engineers can anticipate problems and take steps to avoid them. Additionally, by tracking the evolution of technical debt over time and associating TD types with different stages of the V-model, systems engineers can identify trends and optimize processes to reduce the amount of debt incurred. Leading indicators in systems engineering can be used to provide valuable information about the potential of future risk using technical debt metaphor. By investigating the relationship between leading indicators and technical debt, organizations can identify areas where they may need to invest more resources to avoid or reduce future technical debt. Additionally, this information can help leaders prioritize which areas to focus on to address the issue of technical debt most effectively.

In this paper we address the identification of an association between different types of technical debt and leading indicator trends. This enables the introduction of the concept of technical debt to systems engineering using a well-researched and standardized tool such as “Systems Engineering Leading Indicators Guide” developed by INCOSE. Then we evaluate how it applies to the Hubble Space Telescope case study and we end the paper with a summary.

1. Leading Indicators Definition

A leading indicator is a measure for evaluating the effectiveness of how a specific activity is applied on a project in a manner that provides information about impacts that are likely to affect the system performance objectives¹. Leading indicators support leadership in providing value to clients and end users while offering support in making decisions and taking action to prevent duplication of effort. Additionally, by enabling visibility into anticipated project performance and probable future states, leading indicators promote the efficient management of systems engineering.

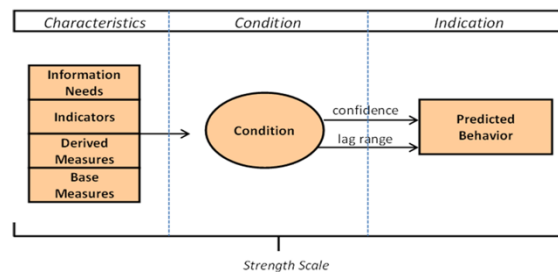


Fig. 1. Leading Indicator Definition¹.

A leading indicator is a predictive tool composed of characteristics, a condition and a predicted behavior¹. The characteristics and condition are analyzed on a periodic or as-needed basis¹. A leading indicator in systems engineering is a measurable value or characteristic that can predict future behavior or conditions, and predictive behavior is the use of leading indicators to forecast and prevent potential problems in a system. For example, in a manufacturing

system, the number of defects in a batch of products could be a leading indicator of the overall quality of the products being produced. If the number of defects is increasing over time, it is likely that the quality of the products will decrease in the future. Another example of a leading indicator in systems engineering could be the average time it takes to complete a task in a production line. If the average time is increasing, it may be a sign that the system is becoming less efficient and that future performance may decline.

Predictive behavior is the use of leading indicators to forecast future behavior or conditions in a system. In the manufacturing example, if the number of defects is increasing, a predictive behavior would be to implement measures to improve the quality of the products, such as increasing inspection and quality control, before the quality of the products declines.

In summary, a leading indicator in systems engineering is a measurable value or characteristic that can predict future behavior or conditions, and predictive behavior is the use of leading indicators to forecast and prevent potential problems in a system.

2. Technical Debt

The term technical debt lacks a standard definition in the systems engineering body of knowledge which is recognized by either INCOSE or IEEE to be the main definition across engineering fields. Some of the most common and most cited technical debt definitions are presented in Table 1.

Table 1. List of Technical Debt most cited Definitions

Technical Debt Definition	Source	Discipline	Year
Technical debt is a metaphor that refers to the consequences of poor software development ²	Cunningham ²	Software Engineering	1992
A design or construction approach that is expedient in the short term, but that creates a technical context in which the same work will cost more to do later than it would cost to do now (including increased cost over time) ³	McConnell ³	Software Engineering	2013
The term technical debt refers to delayed tasks and immature artifacts that constitute a “debt” because they incur extra costs in the future in the form of increased cost of change during evolution and maintenance. ⁴	Avgeriou et al ⁴	Software Engineering	2016

Technical debt is the idea that to create a new software system, you must first create a "mess" that you will eventually have to go back and "clean up." The idea is that it is better to get something working now and worry about making it perfect later. This is often compared to financial debt, where it is better to borrow money now and pay it back later. There are a few benefits to this approach. First, it allows you to get a new system up and running quickly. Second, it gives you a chance to learn from your mistakes and make improvements later. Finally, it can help you manage risk by choosing to work on the most important parts of a project first and adding features later. Of course, there are also some downsides to this approach. First, it can lead to a lot of extra work down the road if not managed properly. Second, it can make it difficult to hand off a project to another team or individual. And finally, it can create technical issues if not done correctly.

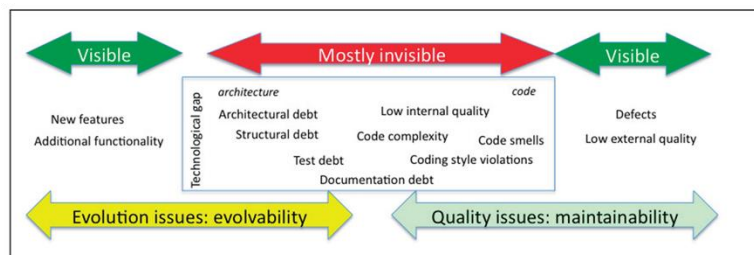


Fig. 2. Technical Debt Definition⁵.

In the figure above using Technical Debt in Software development context, we observe that most technical debt types can be invisible to end users, and they may be categorized the in form of low internal quality or high code complexity. But we find that similar attributes are visible to developers and maintainers when developing code for example, and they those attributes can be visible in the from defects, low external quality and difficulty developing new features.

3. Leading Indicator Trends and Technical Debt Types

INCOSE recognizes 18 leading indicator trends in its systems engineering leading indicators guide¹. Leading indicators are predictive in nature⁶, and they can share this quality with technical debt types. Such qualitative and quantitative measurements can act as enablers to help experienced systems engineering professionals to establish a link between technical debt types and leading indicator trends.

Leading indicator trends focus on already gathered program execution data to determine trends to address. Therefore, leading indicators are technically a reactive measure, although they may be identified during the product development lifecycle and provide significant value during iterative development.

Technical debt management can be a complementary proactive measure, provided technical debt identification starts during the preliminary stages of the product development lifecycle. Consequently, it provides a case-by-case management opportunity for addressing sources of inefficiencies early on to achieve the maximum value.

In the table below, we present a list of technical debt types and leading indicators trends in systems engineering.

Table 2. List of Types of Technical Debt Types and Leading Indicators Trends in Systems Engineering

Types of Technical Debt ⁷	Leading Indicators in Systems Engineering ¹
Requirements TD (Technical Debt)	Requirements Trends
Architectural TD	System Definition
Design TD	Change Backlog Trends
Code TD	Interface Trends
Test TD	Requirements Validation Trends
Build TD	Requirements Verification Trends
Documentation TD	Work Product Approval Trends
Infrastructure TD	Review Action Closure Trends
Versioning TD	Risk Exposure Trends
Defect TD	Risk Handling Trends
	Technology Maturity Trends
	Technical Measurement Trends
	Systems Engineering Staffing & Skills Trends
	Process Compliance Trends
	Facility and Equipment Availability Trends
	Defect/Error Trends
	System Affordability Trends
	Architecture Trends
	Schedule and Cost Pressure

3.1. Illustration of the Link between TD Types and LI Trends using Hubble Space Telescope Case Study

3.1.1. Proposed Mapping of Technical Debt types and Leading Indicators in Test and Evaluation

Leading indicators are predictive in nature, and they can share this quality with technical debt types. Leading indicators are a reactive measure, where Technical Debt tracking is a proactive measure. Such qualitative and quantitative measurements can act as enablers to help experienced systems engineering professionals to establish a link between technical debt types and leading indicator trends.

In the figure 3, we present an initial mapping of technical debt types to leading indicators trends in systems engineering based on the professional experience in the Test and Evaluation of the authors, and a literature review of the existing body of knowledge in Technical Debt.

In this study, we omit the link between risk exposure trends and risk handling trends since they are managed within the systems engineering management context using a risk management framework and are documented in risk registers.

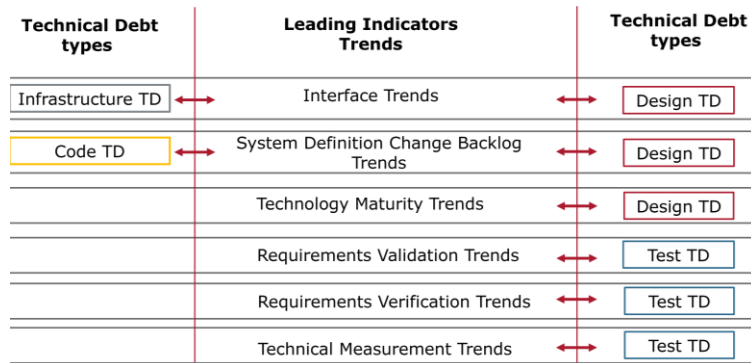


Fig. 3. Proposed Mapping of Technical Debt types and Leading Indicators in Test and Evaluation.

3.1.2. Technical Debt Manifest example using Hubble Space Telescope Case Study

In his study, Terry Bahil identified issues during requirements development, verification, and validation as causes for common failures⁸. We propose to use his analysis to identify examples of leading indicators in systems engineering and how they may be linked to technical debt types based on the analysis of relevant research. Next, we identify integration verification and validation trends that share certain attributes with the technical debt types.

Table 3. Hubble Space Telescope Case Study: Technical Debt to Leading Indicator trends linking Examples

Event	TD Type	Leading indicator
“P-E and NASA (National Aeronautics and Space Administration) both understood and accepted this approach despite a lack of independent measurements to confirm the reliability of the primary test. The failure was not one of system engineering design, but rather one of manufacturing system design and process/quality control. This event occurred at a time when there was also great concern about cost and schedule, overshadowing the obvious need for independent verification testing, or attention to the anomalous RNC data suggesting that something might have been wrong.”⁸	Test Debt	Schedule and Cost Pressure

The exact cause of the spacing error is a matter of conjecture, since the records necessary to reproduce what happened could not be found – another breakdown in technical discipline.⁹ After a long and protracted investigation by officials, the root cause of the calamity was elucidated. A technician had inadvertently inserted a small 3 mm diameter washer into a device called a null corrector, an instrument employed to check the mirror's shape during its production a few years earlier.⁹ Since HST would operate in space and success could not be known with certainty until space performance was observed, the program struggled with ground vs. space approaches, incremental vs. all-up, and the associated cost and risk implications.⁸	Documentation TD Test TD	Process Compliance Trends Requirements Verification Trends
	Design TD Architecture TD Test TD	Technology Maturity Trends

Leading indicator trends and technical debt types are linked in systems engineering because both are used to predict and prevent potential problems in a system. Leading indicator trends are measurable values or characteristics that can predict future behavior or conditions in a system, while technical debt is the cost associated with using a shortcut or suboptimal solution in a system. By analyzing leading indicator trends, systems engineers can identify potential problems and take measures to prevent them. Similarly, by managing technical debt, systems engineers can reduce the potential for future problems and improve the overall performance and efficiency of a system. In this way, both leading indicator trends and technical debt are critical tools in systems engineering for predicting and preventing potential problems in a system.

3.1.3. Technical Debt Manifest example using Hubble Space Telescope Case Study

We use the Hubble Space Telescope Failure Analysis report as a basis for an exemplary exploration. We identify IVV trends in the report data to show leading indicators of systems engineering failures. Next, we establish a link to different technical debt types using exemplary scenarios where we show how a technical debt manifest facilitates the identification of IVV trends and highlights them to the concerned technical teams as well as the program management leadership.

Table 4. Hubble Space Telescope Case Study: Technical Debt Manifest Example

REF#	TD ITEM DESCRIPTION	CATEGORY	SCOPE	COST TO CORRECT	IMPACT (COST TO NOT CORRECTING)	POC/ SUBMITTER
001	Washer added to Null detector to stabilize the primary mirror on the test equipment	Test	Hardware not included in base, short term solution to conduct testing	\$	\$\$\$\$	Test Technician
002	Did not request test documentation from mirror manufacturer	Test	Test documentation and results not delivered by the mirror manufacturer	\$	\$\$\$	Integration Team
003	Mirror post manufacturing measurement and verification	Verification	Primary Mirror's manufactured dimensions did not identically match the design. Accepted to be within tolerance	\$	\$\$\$\$	Verification team

Conclusion

Technical debt is a term that can now be used throughout the entire product development lifecycle, encompassing hardware, software, and systems engineering. It was formerly only used to refer to software engineering. Systems engineers should pay particular attention to technical debt since it affects both product development and program execution, which reduces productivity and raises risk. By making predictions about anticipated project performance and prospective future states, leading indicators help to manage systems engineering projects effectively. Leading indicators also help leadership deliver value to clients and end users while facilitating interventions and actions to prevent duplication of effort and wastage of resources. Here, we consider the connections between several types of technical debt and systems engineering leading indicators. Discovering which of the numerous types of technical debt can be connected to known leading indicators in systems engineering is the main objective of the current study. For systems engineering product development lifecycle to effectively incorporate technical debt tracking, certain connections must be made. We specifically address the issue of whether some forms of technical debt may be described using existing leading indicators trends in systems engineering. We conduct a survey of SME using targeted questions addressing the relationship between IVV (Integration Verification and Validation) trends of leading indicators in systems engineering and several types of technical debt based on a thorough literature research and analysis of the available literature. Based on the study of pertinent research, we explore instances of leading indicators in systems engineering and how they could be connected to various categories of technical debt. Also, we identify integration, verification, and validation trends that share characteristics with different types of technical debt. Experienced systems engineering professionals may be able to establish a connection between several types of technical debt and changes in leading indicators with the aid of the establishment of qualitative and quantitative measurements. As a result, based on the knowledge of experts and an analysis of particular use cases, we propose an initial mapping of technical debt types to leading indicators trends in systems engineering.

References

1. Roedler, G., Rhodes, D. H., Schimmoller, H., & Jones, C. (2010). *"SYSTEMS ENGINEERING LEADING INDICATORS GUIDE" Developed and Published by Members of.*
2. Ward Explains Debt Metaphor. <http://wiki.c2.com/?WardExplainsDebtMetaphor> (accessed Aug. 06, 2022).
3. Technical debt: Towards a crisper definition report on the 4th international workshop on managing technical debt | Request PDF." https://www.researchgate.net/publication/262177984_Technical_debt_Towards_a_crisper_definition_report_on_the_4th_international_workshop_on_managing_technical_debt (accessed Aug. 06, 2022).
4. Lenarduzzi V, Besker T, Taibi D, Martini A, Arcelli Fontana F. A systematic literature review on Technical Debt prioritization: Strategies, processes, factors, and tools. *Journal of Systems and Software*. 2021;171:110827. doi: 10.1016/J.JSS.2020.110827.
5. Kruchten, Philippe B, Robert L. Nord, Ipek Ozkaya and Davide Falessi. "Technical debt: towards a crisper definition report on the 4th international workshop on managing technical debt."
6. C. Orlowski, P. Blessner, T. Blackburn, and B. Olson, "A Framework for Implementing Systems Engineering Leading Indicators for Technical Reviews and Audits," *Procedia Computer Science*, vol. 61, pp. 293–300, Jan. 2015, doi: 10.1016/J.PROCS.2015.09.218.
7. L. A. Rosser and J. H. Norton, "A Systems Perspective on Technical Debt," in *IEEE Aerospace Conference Proceedings*, Mar. 2021, vol. 2021-March. doi: 10.1109/AERO50100.2021.9438359.
8. Terry Bahill, A. and Henderson, S.J. (2005), Requirements development, verification, and validation exhibited in famous failures. *Syst. Engin.*, 8: 1-14. <https://doi.org/10.1002/sys.20017>.
9. Mattice, J.J. (2008). Hubble Space Telescope Systems Engineering Case Study.