

**“Should Costing” and “Tear Down Analysis” Evolving Methods
For Communication Networking Product Industry**

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**“Should Costing” and “Tear Down Analysis” Evolving Methods
For Communication Networking Product Industry**

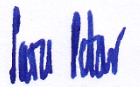
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Dedication

I do dedicate this thesis to Juniper Networks India Pvt. Ltd., the organization which I have been working since 2017 and continuing to help me grow professionally and personally over the past years and also for sponsoring me for this research work. During and slightly ahead of this period, Juniper Networks, due to its own business reasons, allowed me to work on couple of projects that falls in very good alignment with the very same topics that I picked for my research work. I also dedicate this PhD work to my former manager Bernard Glasuer, Senior Director, Supply Chain Operations at Juniper Networks, who stayed as a key motivational factor for me to initiate my route to a research work at this stage of my career. He also motivated me to freely think, participate cross functionally and develop my team to set up an appropriate wing in the team to initiate the execution of these formerly mentioned projects, which really helped me during this research work. I also dedicate this work to my family, parents, neighbors and last but not the least, my fellow engineers and managers at Juniper Networks who really adjusted during my absences whenever I had to stay away from work and life to execute at various stages of this research work!

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ABSTRACT

“Should Costing” and “Tear Down Analysis” Evolving Methods For Communication Networking Product Industry

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While Should Costing and Tear Down analysis are widely considered to be crucial decision-support techniques for addressing the issues of cost transparency and negotiation in the networking industry, they have received limited practical application in the network space with very episodic use and varying reliability. We look at the current use of these techniques, their inhibiting factors for sustained adoption, and the circumstances under which reliable and acceptable organizational cost insight can be gained from using them. The focus is on the challenges of high upfront analytic effort, reducing returns from repeated use, risks of reverse referencing associated with inferred manufacturing equivalence, and the limits on legal, ethical, and intellectual property that such analyses have to work within.

Adopting a qualitative and minimally quantitative, industry-embedded research design blending an extensive review of academic and practitioner literature with semi-structured interviews with representatives from procurement, design engineering, component engineering, manufacturing, and commodity management functions both within and outside the focal organization. This is reinforced by targeted industrial case studies

involving teardown-based cost analysis of networking hardware. This approach to research provides triangulation between expectations from theory, practical, and observed analyses, permitting the study to move beyond prescriptive paradigms and to explore how Should Costing and Tear Down are conducted in complex organizations and supply-chain environments.

The results suggest that the constraints of Should Costing and Tear Down are not due to methodological weakness but to a mismatch between past exhaustive practices and current industrial conditions. The cost factors, as well as perceived diminishing returns, organization deficiencies and supplier resistance were found to be interconnected rather than being independent barriers. The study finds that sequential, architecture-relevant and process embedded techniques can enhance the sustainability and contribution of such techniques. By reframing Should Costing and Tear Down from one-off tools for negotiation to longitudinal learning mechanisms, organizations can better understand costs. They are thus better positioned to meet the legal, ethical and relational risk they face through it. The research offers an empirical view of how developments ought to be made today in the highly dynamic networking product environment.

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CHAPTER I: INTRODUCTION

1.1 Introduction

Telecom products connect the world together. Especially during Covid time we experienced that in-person events were not allowed and that was the time many events were thought could be done virtually as well (people sitting at their respective places and connecting, interacting through an online medium). Companies that make Communication and Networking Products enabled this connection and empowered this change. Such products are usually very highly integrated systems that use hardware and software components. The Hardware components enable electronic, mechanical, and thermal functionalities where software acts as the coordinating function of this hardware. The hardware components used on such products are usually outsourced by Component Manufacturers. Component manufacturers arrive at specific pricing for such components at prescribed functional specifications and their volume of demand. Generally, it is seen as a one-way process where Component Manufacturers arrive at their price and provide as in the form of Quotation to Networking Product companies, who then compare this price with various other preferred manufacturers of their choice and then select from whom they would want to go for the purchase while in production. Also, the New Product Introduction Team (NPI) typically performs the design cycle, introduces the best components and design to their product, gets tests and releases to market (Laubach-Hock, 2011).

This research work mainly focusses on highly integrated products that are used on Communication and Networking purposes but are also highly applicable to various kinds of products/assemblies catering to different industries. The title in the research “Should Costing” and “Tear Down Analysis” are very much applying to any type of products that have multiple hardware, software/firmware components assembled to form the final

product. When Component Suppliers get pricing on a Component/Product they manufacture and/or supply, especially on a newly introduced one to market, where not too much benchmarking is available (Ex: a new design Power Supply Module or Pluggable Optic Transceiver), question is, how do we assess the pricing is reasonable? “Should Costing” (referred as “SC” further in the document) methodology is the major solution available in industry today to help with it. There are many SC models available today, which will get you an idea on sub-component cost, assembly/conversion cost, overheads, logistics, Engineering/Design cost, tooling costs, etc. and provide an indication of how much the overall cost of that Component should be! There have been a lot of research (Ottinger, 1993; Jiang et al., 2022; Sandborn et al., 2006) conducted on SC models and end-to-end methods, but two issues still limit the industries from effectively and commonly using the SC approach in their regular life! One issue is, SC process as such has many challenges (Ottinger, 1993; Jiang et al., 2022), where the industries are stuck about an escape path or solutioning! Second is, even the research conducted in the past has not provided lights on some of these critical challenges (Ottinger, 1993). This research goal is to identify a few critical challenges today in SC method and its implementation at Product Companies and provide incremental solutioning to address them! This research also will include Tear Down analysis (referred as “TD” further in the document) because TD and SC are very closely connected. While conducting SC, you need to essentially perform TD as well. TD provides added advantages to recognize newer Component Technologies, how they are designed to offer various sub-functions within the product (Jiang et al., 2022; Argote and Epple, 1990). So, this research will also identify critical challenges on TD as well and provide incremental solutioning to address some of these challenges.

Key Trends and Perspectives:

Should Costing (sometimes also called as “should-cost analysis” or “should-cost modeling / engineering”) continues to evolve and in 2024–2025 several important new trends are shaping how companies do it (Wallat et al., 2017). At its core, Should Costing is about building a transparent, bottom-up model of what a product or service should really cost — combining material, labor, overhead, logistics, and other cost drivers, rather than just accepting supplier quotes or market prices at face value (Varadarajan, 2013). Because global supply chains have become more volatile, with shifting trade flows, labor cost variations, materials-price inflation, and increasing pressure for sustainability, Should Costing is now more relevant than ever (Longauer et al., 2024; Hayes and Wheelwright, 1984).

A key emerging trend is “Advanced analytics and Predictive cost modeling” (Scognamillo et al., 2025). Should-costing is shifting from a “point-in-time spreadsheet exercise” to a dynamic, data-rich, predictive discipline, more integrated with broader business intelligence. It gives a brief outline of the structure of the body. Another trend in cost modeling is broadening from “manufacturing cost only” to holistic total-cost and value-based modeling, better reflecting real-world complexity and long-term risks and opportunities (Scognamillo et al., 2025).

Supplier collaboration, transparency and development is another trend in SC. SC is evolving toward a strategic, relationship-oriented function, not just a tactical cost-cutting tool. SC is becoming a strategic capability, embedded into supply-chain, engineering, procurement and business-planning decisions, not a standalone exercise (Scognamillo et al., 2025).

These recent trends in SC changing the perspective in industry and SC practitioners are now proposing their companies to invest in digital cost-modeling tools and integrate them

with Enterprise Research Program/Product Life Cycle Management systems (ERP/PLM) (Scognamillo et al., 2025; Miles, 1961). They are expanding the cost models to encompass Total Cost of Ownership, cost-to-serve, and lifecycle costs, rather than focusing only on upfront price and start using cost models not just to negotiate, but to collaborate with suppliers, using transparency, shared cost-driver analysis, and joint optimization (Scognamillo et al., 2025). They are also embedding the cost modeling early in product development, sourcing decisions, and strategic planning, i.e. treat it as a living tool, not a one-time exercise (Scognamillo et al., 2025).

“Teardown analysis” (TD), i.e. the reverse-engineering, disassembly, component trace and structural analysis of networking hardware (performed productively on routers, switches, Wi-Fi access points, etc. (Laubach-Hock, 2011). The overall networking-hardware market was valued around USD 120 billion in 2024 and is projected to grow significantly through 2030–2035 (Laubach-Hock, 2011). and TD is growing from “consumer devices only” to “networking infrastructure”, teardown expanding scope. With networking gear pushing into high-speed domains (multi-gigabit Ethernet, 400 GbE, 800 G, 200 G+ per-lane optical links, dense data-center fabrics), teardown efforts are focusing on high performance switches/routers, merchant-silicon switches, optical interconnects, VCSEL arrays, advanced optics, and high-density PCB/board layout (Laubach-Hock, 2011). Such teardowns help understand power delivery, thermal design, signal integrity, high-speed trace layouts, and innovations that matter for AI-driven and high-throughput data-center workloads (Laubach-Hock, 2011).

1.2 Research Problem

Despite significant academic advancements in Should Costing and teardown analysis, the networking hardware sector, encompassing routers, switches, line cards, and optical transceivers, continues to depend primarily on supplier quotations, historical costing, and

ex-post financial controls rather than analytically derived cost benchmarks (Cooper and Kaplan, 1988; Shank and Govindarajan, 1993). This dependence continues, despite the fact that networking products have high material cost intensity, modular architectures, rapid technology evolution, and short product life cycles, which theoretically make them ideal for should-cost and teardown-based analysis (Baldwin and Clark, 2000; Fine, 1998). Classic theories of should-costing and cost driver emphasize decomposing products and processes to identify the real cause of cost, including the actual materials, manufacturing processes, learning effects, and scale (Wright, 1936; Argote and Epple, 1990; Riley, 1987). Teardown analysis has been proposed as a good way to apply these theories by systematically detaching from product cost structures through disassembling and benchmarking (Ottinger, 1993; Sandborn et al., 2010). Nonetheless, it is known from the experimental findings that traditional teardown approaches are often static and primarily concerned with a bill-of-materials reconstruction approach rather than addressing better process yield, test complexity, reliability requirements, system integration costs etc. (Sandborn et al., 2006; Singh and Das, 2025). These shortcomings are particularly relevant for networking as the scaling of semiconductor chip, optics integration, firmware dependence, and platform reuse will exhibit non-linear and architecture-driven cost drivers that are not well amenable to traditional costing models (Fixson, 2005; Ulrich and Eppinger, 2016). Modularity theory suggests that architectural disassembly should increase clarity about cost attribution, but practice suggests that modular networking systems often hide cost drivers in process knowledge and learning curves of suppliers, leading to less accurate and consistent interpretations of teardown-based estimates (Baldwin and Clark, 2000; Longauer et al., 2024). The literatures discussed make it clear that there has been a major advancement on both “SC” and “TD” in the industry. Most papers have clearly stated about SC models and TD method evolution; however, multiple

challenges remain leading high demand at least to a very common industry adoption not being yet real (Markandya, 2000). Should Costing and teardown analysis are theoretically strong but organizational time-expensive, politically fraught, and strategically fraught, that firms will use them selectively but not routinely. However, in spite of their theoretical rigor, Industrial Application of Should Costing and Teardown analysis is limited by high implementation costs, incomplete observability of major cost drivers, organization-specific capability constraints, strategic pricing effects, and supply and control barriers, forcing firms to selectively use they method instead of widely using them due to their sensitivity (Jiang et al., 2022). Several challenges noted in literature reviews (Ştefea et al., 2008; Kolaczinski, 2006; Adam et al., 2003) are highlighted below (each paragraph addresses each point of view most directly) and I am working to leverage Cost Driver theory and Design Structure Matrix Driver Theory to provide incremental solutions to some of the challenges identified below.

A wide variety of SC and TD models available, which one is appropriate for a particular business is not clearly defined (Kolaczinski, 2006; Xu and Yin, 2023). Many models possess technical and methodological limitations. Teardown cannot see critical cost elements such as yield losses, rework, test coverage, learning curves, overhead structures. (Becker et al., 2020) Also, for each cost models there is dependency on data from very different sources – Bill of Materials (BOMs), Computer Aided Design (CAD) drawings, Enterprise Resource Planning (ERP) tool, supplier quotes, manufacturing process data - and these are often not well integrated. Inaccurate or Incomplete Data is another issue which leads to incomplete analysis and thus is not as productive as expected (Kolaczinski,2006). Dynamic Costs -- Raw material prices, labor, energy, transport - especially in electronics - are volatile, making static cost models quickly outdated (Kolaczinski,2006).

Balancing Detail vs Usability is another challenge -- More detailed cost models (capturing every process / component) are more accurate, but very complex - harder to maintain, validate, and explain (Adam et al.,2003). At the same time, over-simplified models may miss critical cost drivers (e.g., specific process steps, yield losses) that are important in electronics manufacturing (Ștefea et al.,2008). No single method can fully estimate cost; hybrid models are superior. Costs follow stable functional relationships with key engineering parameters. Examples are Die area for IC cost, Fiber alignment tolerance for assembly cost and PCB layers for fabrication cost Hybrid model including Teardown, parametric, expert judgment and learning curves can do better job in bringing a very close cost estimate (Korshunov and Petrushevskaya, 2018).

Another challenge in existing Should Costing methods is that traditional should-costing uses first-order cost drivers (material mass, machining time, labor hours) (Fixson, 2005; Jiang et al., 2022). Cost Driver theory extends this to Second-order cost drivers as well which include Process complexity, Tolerance requirements, Manufacturability (DFA/DFM constraints), Tooling design and amortization nonlinearity. It also extends to Third-order cost drivers such as Supply-chain resilience factors (redundancy, geographic risk), Supplier capability maturity, Learning curves and cumulative production, Volume-risk asymmetry and Quality-capability correlation (Korshunov and Petrushevskaya, 2018).

Cost Driver theory also calls for Transaction-Cost Economics (TCE) Applied to Should-Costing. This used to be a gap in existing Should Costing (Korshunov and Petrushevskaya, 2018). Should-costing under TCE helps decide Make vs buy, Outsourcing vs insourcing, Supplier lock-in risk, Opportunistic behavior, contracting structure (fixed-price vs cost-plus). Supplier pricing is influenced not only by

manufacturing cost but also by transaction costs, which classical should-costing often ignores (Korshunov and Petrushevskaya, 2018).

High upfront cost, uncertain payoff because teardowns require skilled engineers, lab facilities, time-intensive analysis, should-cost models require, detailed process knowledge, continuous updating, Industry reality, ROI (Return on Investment) is unclear unless spend is very high, volumes are large, cost pressure is extreme! (Cooper and Kaplan, 1988) Firms prefer 80% accuracy at 20% effort (benchmarking) over 95% accuracy at 200% effort. (Cooper and Kaplan, 1988).

Diminishing returns after first use is observed in practice. First teardown yields big insights but subsequent teardowns adds only marginal learning. As a result, firms do one-off teardowns, not continuous programs (Cooper and Kaplan, 1991).

Organizational and capability barriers are other issues when it comes to Should Costing and Tear Down. Skills mismatch, need of hybrid expertise such as Design engineering, Manufacturing processes, Cost accounting, Supply-chain economics, etc. These skills sit in different silos. Very few people can integrate with them. Thus, industries often take an approach of outsourcing teardowns or using consultants episodically (Li and Wang, 2024). Also, the knowledge maintenance within the company is a problem connected to what is explained above. Cost drivers such as equipment, yields, labor rates, supplier practices, etc keeps on changing. Maintaining accuracy requires constant model updates. In reality, most firms lack the governance structure to sustain this. Tooling and Resource Constraint is another challenge where specialized tools: X-ray microscopes, SEM (scanning electron microscopes), FIB (focused ion beam), etc. are required. These are expensive and need expert operators. Skilled personnel -- Multidisciplinary teams are required (mechanical, materials, electrical, failure analysis (Bengü, 2010).

Reverse inference risk is another challenge on this topic. Same product is not always following the same process. There could be differences in different factors such as different factories, different automation, different maturity, risks, etc. (Fine, 1998). Another problem is legal, ethical and IP concerns (under-discussed usually). There is always an IP exposure risk. Concerns include reverse engineering proprietary features and crossing legal boundaries in some jurisdictions. Thus, corporate legal teams often restrict systematic teardown programs, antitrust and compliance issues (Porter, 1985). Another challenge is how to ensure supplier Collaboration and Trust -- Suppliers may push back on should-cost models, especially when the buyer uses them as a negotiation weapon. Justifying Assumptions, Validation and Credibility, Complex Assumptions and Risks of misuse found to be other challenges which couldn't see the existing research addressing (Ottinger, 1993). Knowing "true cost" often does not always improve negotiation outcomes. There is risk of supplier alienation. A real industry experience is an aggressive should-cost use signals distrust, triggers defensive behavior, reduces collaboration and suppliers may pad quotes elsewhere, withhold innovation, even exit the business with us (Riley, 1987).

Likewise in Tear Down Analysis one of the challenges that was identified during literature review is with respect to addressing Advanced Packaging Complexity – Integration of multi-functions under single package, fan-out packaging, multi-die stacks, advanced packaging materials, thinness of silicon substrates and fragile structures making TD difficult (Bengü, 2010).

Despite everything above, industry does use Should Costing and teardown analysis, but selectively in cases where high-volume electronics, automotive platforms, defense and aerospace, semiconductor capital equipment, strategic supplier negotiations. It is being generally used directionally, not precisely, as a negotiation reference, not a pricing rule.

(Shank and Govindarajan, 1993). My research is aiming to promote the use of Should Costing and Tear Down Analysis in Networking Equipment industry by finding incremental solutions to some of the challenges listed above.

Other challenges that will be out of scope for my research work include a few examples as listed below.

During Should Costing and tear down discussions with suppliers' strategic opacity is intentional. Buyers or customers do not want perfect cost transparency, reason being for flexibility in negotiation, avoiding commitment to "fair price" logic, etc. (Shehab and Abdalla, 2002). Miniaturization, over-molding, and chip-scale packaging prevent clean disassembly and thus impede Tear Down. Classical teardown isolates components but fails to capture Optical–electrical–thermal coupling and Control firmware–hardware co-dependence. Emerging Industry Challenges (2020s–Present) on Software-Defined Value. There is for sure increasing cost and value in software, algorithms, and firmware Teardown is limited with physical disassembly missing software economics (Shehab and Abdalla, 2002).

In addition, there is a persistent theory–practice divide. While the academic literature promotes analytically rigorous frameworks, such as activity-based costing and time-driven activity-based costing, to encourage strategic decision-making (Li and Wang, 2024; Kaplan and Anderson, 2004), their adoption in industry is still limited owing to high data collection costs, confidentiality barriers, skill requirements, and uncertainty regarding model credibility (Cescon, 2019; Varadarajan, 2013). Consequently, teardown and should-cost analyses are often pushed into educational, exploratory, or post-hoc benchmarking roles rather than integrated into early-stage design, sourcing, and make-or-buy decisions (Sandborn et al., 2010; Becker et al., 2020). As a result, current methods do not adequately accommodate cost–performance trade-offs, supplier negotiation, and

architecture selection in complex networking products, such as optics- and semiconductor-intensive subsystems. This brings to light an urgent research gap: a networking-specific, theory-grounded, and empirically validated approach for should-costing and teardown, integrating product architecture, manufacturing processes, learning effects, and system-level constraints at all phases of the networking hardware lifecycle.

1.3 Purpose of Research

Focus is to conduct a study on existing SC theories and provide a general idea on TD/Benchmarking studies. Literature Review was conducted (Ottinger, 1993; Jiang et al., 2022; Sandborn et al., 2006) with an objective to assess if it really makes sense to invest time on doing research on this topic. The literature review focused to find out existing critical challenges in SC and TD. It also focused on finding out if there are already released research papers addressing these challenges or still there are many open, without a solution! Literatures cited in Bibliography section were reviewed and could understand that there are many challenges in SC and TD methods and their implementation to Product companies. Also observed gaps in Academic Research works done in the past, which really don't address many of these major challenges (Ottinger, 1993; Jiang et al., 2022; Baldwin and Clark, 2000).

The goal of this study is to help networking companies figure out how much their products should cost without relying too much on quotes from suppliers or past cost data. Networking products like routers, switches, and optical transceivers are hard to understand and expensive, but many people still make decisions about how much to spend without knowing what factors affect the cost (Cooper and Kaplan, 1988; Varadarajan, 2013).

The purpose of this study is to adapt existing work in that the teardown analysis was conducted as a systematic procedure, which can be used to evaluate product cost.

Teardown analysis involves a full dismantling of the items to gain critical information about the parts, materials, and manufacturing specifications. Previous literature has suggested that teardown analysis may help in cost modeling and benchmarking but is normally only used in restricted or schooling contexts (Ottinger, 1993; Sandborn et al., 2010). Among the primary objectives of this study is to identify much more than only components, and to consider several critical component features which are determinants of the cost of networking hardware, such as the product's structure, design, testing process and the development of learning methods. Research is showing that learning curve and manufacturing experience can significantly reduce the costs, especially for electronics and semiconductor-manufacturing products (Wright, 1936; Argote and Epple, 1990). Similarly, the modularity of product architectures can mask cost drivers or expose how cost drivers manifest, depending on architectural configuration (Baldwin and Clark, 2000). This work aims to clarify should-costing processes to become more applicable and reliable for businesses. Although academic methods of study (in particular activity-based costing) offer excellent theoretical frameworks, they are considered too abstract or data-hungry for routine industrial decision-making (Cooper and Kaplan, 1991; Kaplan and Anderson, 2004). By relating teardown observations directly to established cost drivers, this research aims to address some of the present challenges in Should Costing and Tear Down analysis. The study also aims to show the worth of the proposed solution with actual networking hardware scenarios. Through that it aims to provide evidence on how enhanced should costing and teardown analysis could lead to more effective design choices, more intelligent make-or-buy decisions, and more successful supplier discussions in the networking industry (Sandborn et al., 2010; Jiang et al., 2022).

1.4 Significance of the Study

SC and TD matter a lot to the industry because of, Negotiation Leverage: More academic cost models (and validated ones) can increase the credibility of should-cost estimates during supplier negotiations. Companies want to use SC and TD methods for Sustainability: As companies increasingly value environmental costs, integrating carbon or resource-use metrics into should-cost models helps align procurement with Environmental standard goals (Wallat et al., 2017). These methodologies help companies on Strategic Decision Making: Better cost models support make-or-buy, capacity planning, and fab investment decisions. SC and TD are good tools for Risk Management: Understanding cost variability, yield sensitivity helps companies build more resilient cost models (Scognamillo et al.,2025). TD specifically helps in Design Optimization: If cost models feed back into design (e.g., knowing which process steps or packaging contribute most to cost), designers can make more cost-aware decisions early on (Courbon,2020). TD reveals true cost structure (BOM + process cost + assembly) and becomes the backbone for should-costing, cost-down negotiations, design-to-cost redesign, benchmarking against competitors. TD exposes hidden design decisions and engineering trade-offs and identifies IP strategy, architecture, and future direction. TD guides future product design (DFM/DFX) and accelerates innovation. Thus, it still carries a lot of weightages in exploring further on SC and TD. Work towards finding solutions for some of the challenges existing today!

Should Costing (sometimes also called as “should-cost analysis” or “should-cost modeling / engineering”) continues to evolve and in 2024–2025 several important new trends are shaping how companies do it (Wallat et al., 2017). At its core, Should Costing is about building a transparent, bottom-up model of what a product or service should really cost, combining material, labor, overhead, logistics, and other cost drivers, rather

than just accepting supplier quotes or market prices at face value (Varadarajan, 2013). Done well, it serves multiple roles: a negotiation tool, a baseline for cost transparency, input to make-vs-buy decisions (insourcing vs outsourcing), and a foundation for supplier collaboration and long-term cost control (Longauer et al., 2024). Because global supply chains have become more volatile, with shifting trade flows, labor cost variations, materials-price inflation, and increasing pressure for sustainability, Should Costing is now more relevant than ever (Longauer et al., 2024; Hayes and Wheelwright, 1984). “Teardown analysis” (TD), i.e. the reverse-engineering, disassembly, component trace and structural analysis of networking hardware (performed productively on routers, switches, Wi-Fi access points, etc. (Laubach-Hock, 2011). The overall networking-hardware market was valued around USD 120 billion in 2024 and is projected to grow significantly through 2030–2035 (Laubach-Hock, 2011). and TD is growing from “consumer devices only” to “networking infrastructure”, teardown expanding scope. With networking gear pushing into high-speed domains (multi-gigabit Ethernet, 400 GbE, 800 G, 200 G+ per-lane optical links, dense data-center fabrics), teardown efforts are focusing on high performance switches/routers, merchant-silicon switches, optical interconnects, VCSEL arrays, advanced optics, and high-density PCB/board layout (Laubach-Hock, 2011). Such teardowns help understand power delivery, thermal design, signal integrity, high-speed trace layouts, and innovations that matter for AI-driven and high-throughput data-center workloads (Laubach-Hock, 2011).

When organizations don’t have anything with them about SC and TD, they are totally screwed by the suppliers, especially on new technologies, new product releases! Very big examples are the newer model Cell Phones, latest Pluggable Optics transceiver modules and many more! In case of Pluggable Optics Transceiver modules, the 800G model is more than 24,000 USD (Longauer et al., 2024), whereas a matured pluggable only costs

in tune of <1000 USD! The idea here is not to jump onto every supplier on everything they do, but is to apply on some key models, key suppliers where it can yield both parties a win-win situation (for both Supplier and Customers).

From the set of literature reviewed, it was clear that a very few academic papers attempt (Sato, 2005) a full “bottom-up should-cost” model covering all cost elements (fab Operating Expenses (OPEX), Capital Expenses (CAPEX), test, packaging, yield, scrap, etc.). Thus, an End-to-End approach on SC and TD found to be missing in the papers reviewed! While some papers (Olabisi et al., 2014; Sandborn et al., 2006) look at carbon/emissions, there’s less work on integrating operational cost, environmental cost, and regulation cost into unified should-cost frameworks. Not many studies (Laubach-Hock, 2011) have been done on how to effectively utilize AI/ML for Cost Modeling. No papers were spot that addressed how Should Costing be used as driver for Make-or-Buy Decision making. Very limited studies (Rains,2008; Singh and Das, 2025) on how to benchmark and validate the SC outcome arrived at. Most importantly, effective ways of supplier collaboration: Not many papers talk about how the SC could be used as a win-win liver so that supplier resistance could be minimized, and all effectiveness could still be realized (Angelis,2015). Most importantly many of the critical challenges are not touched in any of these research papers (Varadarajan, 2013) and are thus staying as roadblocks to the widespread use of SC and TD!

1.5 Research Purpose and Questions

The purpose of the research is to use the already existing developments, and available research works to arrive at an effective Should Costing and Tear Down Analysis process including tool and method recommendations to perform Should Costing and Tear Down analysis on products used in modern Communication Networking. The products in Networking comprise of assembled subcomponents as well, the intended scope

application includes them too. Examples of such assembled subcomponents are Power Supply Units (PSUs), Pluggable Optical Transceivers, Cable Assemblies, etc. As indicated previously in this document, various challenges in Should Costing and Tear Down is blocking the frequent use of these in Networking Industry. The idea from this research is to provide as much incremental help to enable more frequent application of Should Costing and Tear Down as an information gathering, benchmarking and continuous learning system for new Designs as well as a collaborative lever for cost discussions with key vendors and partners.

Also, the objective of the current study is to provide a comprehensive review of literature and industry practices in relation to Should Costing and Tear Down Analysis and outline a conceptual framework for these. To achieve the above purpose, this research is guided by the following questions:

RQ1: What are the Should Costing and Tear Down techniques/methods available today in Networking Industry? What are their advantages and disadvantages?

RQ2: How can teardown analysis be systematically used to identify and quantify key cost drivers in networking products?

RQ3: What are the most appropriate tools and methods on Should Costing and Tear Down suitable to products in Networking Industry, that provides incremental solutions to some of today's challenges in Should Costing and Tear Down?

RQ4: What methods could be adopted to address the high upfront cost and diminishing returns of Should Costing and Tear Down? Any incremental solutions possible here?

How to overcome the Organization Capability Barriers that impede the frequent application of Should Costing and Tear Down.

RQ5: To arrive at methods to handle the issue of Reverse Referencing Risk (RRR), which is about wrong assumptions by Should Costing/Tear Down team about

same/similar product is equal to same manufacturing process (Longauer et al., 2024).

Define as to in which cases this policy of “same process” applies vs which cases it needs reassessment to find out the manufacturing process.

RQ6: What are the legal, ethical and IP concerns while doing Should Costing and Tear Down?

RQ7: How Should Costing and Tear Down could be effectively utilized in supplier collaboration as opposed to supplier push backs and stiffening relationships, which is at present one of the biggest challenges (Longauer et al., 2024) in wider adoption of Should Costing and Tear Down techniques in Networking industry?

CHAPTER II: REVIEW OF LITERATURE

2.1 Theoretical Framework

A preliminary literature review shows that past studies (Longauer et al., 2024; Hayes and Wheelwright, 1984) are primarily focused on understanding and modeling a particular type of constraint, such as technological, contractual, resource, spatial, and information constraints. Limited progress has been made on classifying various constraints according to their characteristics in a comprehensive manner. In terms of modeling and resolving constraints, various approaches have been recommended. For example, many CPM-based methods are applied to deal with time-related constraints; knowledge-based systems were used to automate work plan generation; network-based optimization algorithms were developed to resolve constraints; and databases and visualization techniques, such as 3D, 4D, and Virtual Reality (VR), are used to communicate and visualize constraints (Chen et al., 2023; Wang et al., 2023). What is missing from the past studies is a comprehensive and structured approach in managing constraints. What is missing from the past studies is a comprehensive and structured approach in managing constraints.

A preliminary literature review on past studies shows that Should Costing (sometimes also called as “should-cost analysis” or “should-cost modeling / engineering”) is now more relevant than ever (Longauer et al., 2024; Hayes and Wheelwright, 1984) because global supply chains have become more volatile, with shifting trade flows, labor cost variations, materials-price inflation, and increasing pressure for sustainability. It continued to evolve and in 2024–2025 several important new trends are shaping how companies do it (Singh and Kaur, 2025; Wang et al., 2023). At its core, Should Costing is about building a transparent, bottom-up model of what a product or service should really cost combining material, labor, overhead, logistics, and other cost drivers, rather than just accepting supplier quotes or market prices at face value (Varadarajan, 2013). Done well,

it serves multiple roles: a negotiation tool, a baseline for cost transparency, input to make-vs-buy decisions (insourcing vs outsourcing), and a foundation for supplier collaboration and long-term cost control (Longauer et al., 2024).

A key emerging trend observed from literatures reviewed (Longauer et al., 2024; Hayes and Wheelwright, 1984; Scognamillo et al., 2025) is “Advanced analytics and Predictive cost modeling”. Should-costing is shifting from a “point-in-time spreadsheet exercise” to a dynamic, data-rich, predictive discipline, more integrated with broader business intelligence. It gives a brief outline of the structure of the body. Another trend in cost modeling is broadening from “manufacturing cost only” to holistic total-cost and value-based modeling, better reflecting real-world complexity and long-term risks and opportunities (Scognamillo et al., 2025).

Supplier collaboration, transparency and development is another trend in SC. SC is evolving toward a strategic, relationship-oriented function, not just a tactical cost-cutting tool. SC is becoming a strategic capability, embedded into supply-chain, engineering, procurement and business-planning decisions, not a standalone exercise (Scognamillo et al., 2025).

These recent trends in SC changing the perspective in industry and SC practitioners are now proposing their companies to invest in digital cost-modeling tools and integrate them with Enterprise Resource Planning/Product Life Cycle Management systems (ERP/PLM) (Scognamillo et al., 2025; Miles, 1961). They are expanding the cost models to encompass Total Cost of Ownership, cost-to-serve, and lifecycle costs, rather than focusing only on upfront price and start using cost models not just to negotiate, but to collaborate with suppliers, using transparency, shared cost-driver analysis, and joint optimization (Scognamillo et al., 2025). They are also embedding the cost modeling early

in product development, sourcing decisions, and strategic planning, i.e. treat it as a living tool, not a one-time exercise (Scognamillo et al., 2025).

“Teardown analysis” (TD), i.e. the reverse-engineering, disassembly, component trace and structural analysis of networking hardware (performed productively on routers, switches, Wi-Fi access points, etc. (Laubach-Hock, 2011). The overall networking-hardware market was valued around USD 120 billion in 2024 and is projected to grow significantly through 2030–2035 (Laubach-Hock, 2011). and TD is growing from “consumer devices only” to “networking infrastructure”, teardown expanding scope. With networking gear pushing into high-speed domains (multi-gigabit Ethernet, 400 GbE, 800 G, 200 G+ per-lane optical links, dense data-center fabrics), teardown efforts are focusing on high performance switches/routers, merchant-silicon switches, optical interconnects, VCSEL arrays, advanced optics, and high-density PCB/board layout (Laubach-Hock, 2011). Such teardowns help understand power delivery, thermal design, signal integrity, high-speed trace layouts, and innovations that matter for AI-driven and high-throughput data-center workloads (Laubach-Hock, 2011).

Through the literature review a clear understanding was made on key trends and perspectives in Should Costing and Teardown Analysis. The literature review helped in studying about where SC and TD has arrived as of today. It also given lights to next step advancements in SC and TD as listed below!

Formalizing teardown as a “knowledge-generation / design-learning” method for designers, RandD, innovation, beyond reverse-engineering (Otto and Wood, 2001). Hierarchical Cost Breakdown Structure (CBS) linked to function and architecture. CBS derived from Teardown Bill of Materials, dynamic CBS for iterative design changes. Process-Based Cost Modeling (PBCM) enables highly defensible cost estimates for

PCBs, ASICs, mechanical housings, Thermal components, High-volume manufacturing lines (e.g., routers, IoT, telecom gear) (Otto and Wood, 2001).

"Bottom-Up vs. Top-Down Should Costing is trending towards Hybrid Approach. Use top-down to set boundaries; bottom-up for accuracy. Parametric Cost Modeling using ML-based parametric models using manufacturing datasets. Supplier Economics and Should-Cost frameworks link supplier economics to global value-chain models, currency fluctuation scenarios, learning-curve effects (Wright's law) (Boothroyd et al., 2011). Modern Design-for-Cost (DfC) includes Design for supply-chain resiliency, Design for circularity and recycling, Cost-aware generative design (AI) (Ulrich and Eppinger, 2016). AI-Augmented Should Costing (Emerging): Vision-based BOM extraction from teardown images, ML-based prediction of manufacturing process parameters, automated CBS generation from CAD / STEP (Mechanical design) files (López and Díaz, 2024). From 1st set of the literatures reviewed it's clear that industry has progressed a lot on "SC" and "TD". The papers (Meyer and Zhou, 2024; Jiang et al., 2022; Patel and Mehta, 2024). clearly indicated about evolution of SC models and TD methods, still there are multiple challenges due to which a very common industry adoption is not yet real (Kalir, 2023). Examples of reasons for not such wider implementation is explained in the "Problem Statement" section of this document.

From the 2nd set of literature reviewed, it was clear that a very few academic papers attempt (Berk, 2010; Cescon, 2019) a full "bottom-up should-cost" model covering all cost elements (fab Operating Expenses (OPEX), Capital Expenses (CAPEX), test, packaging, yield, scrap, etc.). Thus, an End-to-End approach on SC and TD found to be missing in the papers reviewed! While some papers (Ottinger, 1993; Jiang et al., 2022; Sandborn et al., 2006) look at carbon/emissions, there's less work on integrating operational cost, environmental cost, and regulation cost into unified should-cost

frameworks. Not many studies (Ottinger, 1993; Jiang et al., 2022; Sandborn et al., 2006) have been done on how to effectively utilize AI/ML for Cost Modeling. No papers were spot that addressed how Should Costing be used as driver for Make-or-Buy Decision making. Very limited studies (Ottinger, 1993; Jiang et al., 2022; Sandborn et al., 2006) on how to benchmark and validate the SC outcome arrived at. Most importantly, effective ways of supplier collaboration: Not many papers talk about how the SC could be used as a win-win liver so that supplier resistance could be minimized, and all effectiveness could still be realized (Angelis and Nussbaum, 2015). Most importantly many of the critical challenges are not touched in any of these research papers (Varadarajan, 2013) and are thus staying as roadblocks to the widespread use of SC and TD!

Cost management in technology-heavy industries has changed from traditional accounting-based methods to analytical, engineering-driven methods that allow for transparency, control, and strategic decision-making. In the networking environment that encompasses complex product architectures, rapid technological progress, as well as global networks where the supply of goods to businesses increases, Should Costing and teardown analysis have become indispensable tools for analyzing both cost structures of products and pricing behaviour of suppliers (Argote and Epple, 1990; Lee and Park, 2024). These methods are theoretically grounded on cost engineering theory, transaction cost economics, learning curve theory and modular systems theory, in order to clarify the influence of product design, manufacture processes and organisational capabilities, on cost effects (Argote and Epple, 1990; Baldwin and Clark, 2000). This section combines this theory and develops a methodology linking teardown and Should Costing on cost transparency and procurement effectiveness in the networking environment. Different theories are analyzed with the final decision on the most appropriate theory in Should Costing and Tear Down analysis. We will elaborate upon them in the following sections

of this research paper. Should Costing as a Cost Engineering Theory: Should Costing is founded on normative cost theory aimed at the identification of the most economical method to prepare a product and achieve its optimal performance as such cost-effectively as possible, rather than relying on market prices or supplier quotes (Angelis and Nussbaum, 2015). The "should cost" is a value-oriented theoretical benchmark based on engineering specifications, production processes, material prices, labor, overhead and profit margins. According to cost engineering literature, Should Costing is classified as a bottom-up analytical methodology where the product cost is broken down into measurable and manageable units of measurement (Rush and Roy, 2001). This supports the activity-based costing framework examining the link between activity and costs. But it will go a step further by considering the feasibility of building and making designs. On networking equipment such as switches, routers and optical modules, Should Costing tells companies how much high value equipment components, like ASICs, PCBs, optical transceivers and thermal-management systems would be priced should Costing be done. So, Should Costing is not only an attempt to establish prices but a strategy device, linking construction design decisions to the purchase policy, the sourcing, and so on.

Should Costing and Transaction Cost Economics Theory: According to transaction cost economics (TCE) the supplier price often indicates that buyers and suppliers do not have identical information (Williamson, 1985). For complex technology goods, suppliers generally possess more understanding than anyone else regarding production costs. In this way, they are free to include risk premiums or inefficiencies in their pricing calculations. Should Costing remedies this imbalance by translating implicit manufacturing knowledge into cost models that are visible to everyone. This reduces uncertainty about buyer-supplier transactions and the likelihood of exploitation (Angelis and Nussbaum, 2015). Should Costing makes more efficient the governance mechanisms

for networking supply chains—where OEMs depend on the provision of specialized components—based upon facts and contracts. Teardown analysis is based upon the model of reverse engineering that studies the process of generating design, functional, and cost information from existing products (Otto and Wood, 2001). Teardown analysis allows you to piece together what a product looks like, the selection of material, processes of manufacturing, and the complexity of assembly. In theory, teardown analysis supports cost estimating models by verifying assumptions related to quantity or quantity of components produced, type of material chosen, level of manufacturing carried out (Sandborn et al., 2009). This empirical grounding is highly relevant to networking products as cost drivers are written into the design of multilayer PCB systems, high-speed interconnects, and integration of silicon levels.

Modularity Theory and Teardown Analysis (Ferreira and Oliveira, 2021) modularity theory, provides us with a way to present teardown results from a different perspective. To scale and modernize networking equipment as easily as possible, we are increasingly applying modular architectures, like pluggable optics, line cards and modular power supplies. Teardown analysis gives you modular boundaries and interfaces. This allows cost analysts to see how modularization changes the cost of making something, how dependent you are on suppliers, how to use economies of scale. In theory, greater modularity can reduce coordination costs and enhance learning effects. But it also introduces new costs for interfaces and duplication, and therefore the potential for the user to have the same interfaces that have a negative impact on the overall economics of the product as well (Ferreira and Oliveira, 2021).

Blending Teardown with Should Costing: It is said in the literature that teardown analysis and Should Costing are two methods to make sense of things; at least, this is always true. Teardown analysis shows us concrete examples of how products are combined and the

parts one contains. By contrast, Should Costing, in this context, converts this information into cost models (Rush and Roy, 2001; Angelis and Nussbaum, 2015). In theory, teardown analysis is an observational construct, while Should Costing is an analytical construct. Used in conjunction, they enable triangulation between physical evidence and theory so that material fact and cost drivers can be compared with the theoretical ones, which in turn result in cost estimates that tend to be closer together. Theory of learning curve and costs reduction: according to learning curve theory, unit costs decrease as overall production volume increases due to learning and efficiency savings that result from larger learning curves (Debnath et al., 2025).

Teardown analysis can be used to identify where the ‘learning effects’ are largest: constructing PCBs, aligning optics or testing networking equipment automatically. Employing learning curve assumptions in their should cost models enables companies to estimate dynamically the changes costs will undergo. This informs long-range decisions about sourcing and pricing. The need for such integration is particularly critical in networking markets, where technology adoption cycles result in rapid volume scaling. That is, following the literature that was reviewed, we can deduce a theoretical guide into some propositions such as these as follows. Teardown analysis provides us with practical information on the structure of a product, its components and how difficult it is to manufacture it. Should cost models apply engineering and economic concepts to determine just how high or low the cost is of producing something in a proper time span. These insights help with that. Lowered Cost Transparency makes it easier to negotiate with suppliers by lowering the amount of information that is not shared. More openness leads to better Procurement Performance, which includes saving money, getting suppliers on the same page, and making strategic sourcing decisions. This framework sees teardown analysis as a tool that makes other things possible and Should Costing as the

main analytical tool that connects product design and procurement results in the networking industry. Even though Should Costing and teardown analysis are widely used in practice, there aren't many academic papers that talk about them in the context of networking equipment. Most of the studies that have been done so far are either general or only look at consumer electronics and defense systems.

This research contributes theoretically by contextualising cost engineering and reverse engineering theories within the networking industry, integrating modularity and learning curve perspectives into a unified framework. Such a framework advances scholarly understanding of how design complexity and technological evolution shape cost structures in high-technology manufacturing sectors.

With this research I intend to demonstrate that SC and TD are very much value adding techniques to Networking Industry. Even though there are challenges where industry is stuck or thus the usages of such techniques are limited, this study is intended to give clarity on some of those and provide incremental approaches to tackling such challenges! Through literature review, I could arrive at two main theories which can potentially provide solutions to some of the challenges Should Costing and Tear Down. These theories are “Cost Driver Theory in Should Costing” and “Design Structure Matrix (DSM) Driver Teardown Theory”.

2.2 Cost-Driver Theory in Should Costing

The key question asked during Should Costing is “What should a product cost, given its design, materials, processes, and supply chain?”. The literature review observed gaps in Academic Research works done in the past, which really don't address many of the major challenges in Should Costing (Ottinger, 1993; Jiang et al., 2022; Patel and Mehta, 2024). Thus, the focus of this research is to propose an end to end Should Costing and tear down

analysis process, addressing some of the existing key challenges! The cost driver theory is a step towards the same.

In industries that rely heavily on technology, cost management has moved away from traditional accounting and price-based methods and toward analytical frameworks that show why costs arise and how design, engineering, and procurement choices can change them. In this context, Should Costing, a structured way to figure out how much a product should cost under ideal conditions, has become a key tool for getting cost transparency and making procurement work better. Cost Driver Theory is the analytical framework that lies at the heart of Should Costing. It explains the factors that cause costs to behave in certain ways. This analysis is especially important for networking products like routers, switches, optical transceivers, and high-speed line cards. These products have complicated architectures, advanced silicon designs, complicated assembly processes, and tightly linked system interactions.

This chapter provides a thorough theoretical framework for cost driver theory in the context of Should Costing within the networking sector. It asks questions about how cost drivers are defined and used in practice, how they relate to current problems with cost estimation, and how they help make strategic choices about design, manufacturing, and sourcing. It begins with a definition of Cost Drivers.

A cost driver, on the other hand, is a variable that directly affects the cost of an activity, component, or system (Cooper and Kaplan, 1988). Cost driver theory is distinct from volume-based cost allocations in that it is causal, maintaining that cost behavior is only understood through the identification of fundamental determinants of cost, including design complexity, process requirements, type of technology adopted, and implementation of the structure of an organization (Porter, 1985). Cost drivers provide a lens through which we can analyze the relationship between physical products and

economic results. Cost drivers are the cornerstones of Should Costing bottom-up models. These models decompose total cost into quantifiable parts. Price quotes from suppliers, an area of data that Should Costing does not address, can be distorted by information asymmetry and market distortions. It relies on cost drivers to develop a defensible, engineering-based cost benchmark (Chen et al., 2021). Such a benchmark is helpful for any negotiation or decision on design and sourcing plans. Typically, cost drivers fall into one of two groups: structural cost drivers and executional cost drivers. Structural cost drivers are long-term strategic factors that are embedded in product architecture, technology, and organizational decision making (Porter, 1985). Executional cost drivers are also a form of cost driver. This is because their operational drivers show how the activities are done -- including, but not limited to, manufacturing yield, automation level, or process maturity. This categorization is very significant in networking products because the structural factors (e.g., ASIC vs. merchant silicon and modular design options) have long-term consequences for cost while the executional factors (such as test automation and yield improvements) determine how well a product works. The theoretical basis of Should Costing models is based on these structural and executional drivers. They also demonstrate causes and sources of cost/change. In the section that follows, we will be taking a closer look into the concept of Networking Product Architecture and its costs. New networking products have multilayered architectures consisting of both digital and analog circuitry, high-speed interconnects, advanced thermal management, and embedded software. These features create various cost drivers that interact with each other. One of the key aspects to consider is ASIC and Silicon Integration. Custom ASICs are among top costs of routers and switches with high capacity. Considerations about silicon, such as whether to use fully custom ASICs or

merchant network processors, directly impact fixed cost and variable cost (Zhang and Li, 2025).

While custom ASICs are generally superior, they must pay more for NRE and have greater yield variability, especially at advanced process nodes. Merchant silicon can reduce NRE but may also make it more difficult to distinguish a product. Cost driver theory claims that the technology we choose is a structural cost driver (Kim and Choi, 2023). That means it has influences on silicon cost directly but also on how the board is designed, the cooling system in place, and how complex it is to test. Hence, the Should Costing model should explicitly incorporate silicon strategy as a driver as opposed to just an additional cost input. Another point worth considering when undertaking Should Costing for Networking Products is PCB Complexity and Integration. The multilayer PCBs that often comprise networking electronics have high signal integrity requirements, need controlled impedance traces, blind or buried vias, and many components clustered together. These characteristics make it more difficult to create things, more challenging to assess, and riskier to produce a desirable yield, each one adding to the cost. Cost driver theory focuses on the causal relationship of physical design specifications (layer count, via density) and cost consequences. Can measuring these links also help Costing differentiate between the costs that are required for the design and the areas that can be improved? Executional cost drivers come into play in manufacturing and assembly once the product architecture comes into play. It highlights a few cost drivers in the executional piece of work (Zhang and Li, 2025).

Performance Standards: Since high-speed networking boards and optical modules have very high performance standards, testing them must be done very carefully. Loss of yield, especially in high-layer PCBs or silicon modules, is a major cost driver that cannot be ignored. According to cost driver theory, yield variability is no longer random noise, but

rather a systematic effect caused by design decisions and process capability. It has been reported that in Should Costing, yield and test time are treated as separate drivers; measured drivers and therefore cost drivers and their dependence is treated as such; both yield and test time are also considered independent drivers that are estimated by quantity and have an effect on costs making the cost model more efficient and the forecasts of cost are closer to prediction (Zhang and Li, 2025). This is a significant departure from the old method, which may consider test costs as general overhead. Learning effects and automation are two additional things that can increase execution costs. Unit costs decrease with increasing production volume, reflecting increased knowledge and increased process efficiency (Debnath et al., 2025), according to learning curve theory. In networking hardware, to begin with, automating assembly and testing can make learning something very difficult, but over time can save money on labor and rework. Learning effects are executional drivers of cost driver theory. Thus, the Should Costing may vary with production experience over time. This is relevant in technology markets that move quickly -- cost of first order input of technology is high but gradually drops as work rate goes up. Here is a brief overview of the issues of Should Costing and the place of Cost Driver Theory. The literature review identified many issues (Zhang and Li, 2025; Debnath et al., 2025). One of which is making products more complex. The more things (routing, switching, security in particular) that networking products combine into one platform, the harder it is to figure out how much they'll cost. Traditional costing methods find it difficult to catch up because complexity is treated by them not as an independent input of cost. Cost driver theory solves this by identifying specific architecture and process drivers such as functional blocks, interconnect density and protocol processing needs and mapping them to parametric cost models. Thus, instead of simply 'adding up' costs, Should Costing should explain how the system was designed, for example. Another

issue is that suppliers don't always have that information. Specialized vendors offer critical parts, such as ASICs and optical modules, which they can see much more clearly than others, at a fraction of their competitors in terms of costs. This results in information asymmetry, a widely perceived problem in transaction cost economics (Williamson, 1985). If buyers only look at supplier quotes, they will often end up paying more than they're worth or paying for the unknown cost that is not transparent. Thus, cost driver theory alleviates this imbalance: it converts features you engineer into cost drivers that don't hinge on supplier price setting mechanisms. Should Costing turns negotiated prices into benchmarks through which to compare supplier offers, rather than simply taking them at face value. Another major issue with Should Costing is that technology is always evolving. Networking standards shift fast (for example, from 100G to 400G to 800G), which means that cost structure changes frequently. Static cost models get useless very fast when you don't know how they work. Adaptive costing is made possible by cost driver theory which ties cost drivers to technology parameters [such as signal rate, power density, process node etc.]. As technology alters, so do the things that drive it. This means that should costing models can be updated by following logic rather than experience. Another issue is supply chain volatility, which makes it difficult to forecast costs owing to global supply interruptions, shifts in the price of materials, and geopolitical tensions (Longauer et al., 2024).

Cost driver theory allows sensitivity analysis by identifying what drivers (e.g., raw material cost, lead time penalties, capacity constraints) are most susceptible to external shocks (Longauer et al., 2024). This allows the teams responsible for purchasing and designing plan for the worst to make decisions that will endure. In the succeeding section, we will discuss the implications of Cost Driver Theory on Should Costing Practice. Cost driver theory is support to parametric modeling as we can find the cost because of

measurable factors. In networking products, the quantity of ASIC gates and process nodes, the quantity of PCB layers and the physical area, the quantity of optical channels and wavelength and number of test vectors are generally used cost drivers. Should Costing can predict rather than just snapshots to keep tracking points down as parametric models are statistically perfect when calibrated or when built on teardown information. In theory, cost driver theory is the modification of a market-based exercise called Should Costing to a system for using feedback on engineering design (Kalir, 2023; Jiang et al., 2022). For example, designers can see how much architectural change will cost if they measure how established cost drivers will change. If you add lots of memory buffers or ports increase, e.g. more: I may start to go after things that need extra data. This feedback loop allows designers to consider costs for choices, and joins engineering and procurement. This study confirms cost driver theory as the only main theoretical theory which makes Should Costing analytically sound and practically useful. It integrates engineering design, manufacturing performance and economic outcomes as one single framework to explain how costs act in complex technology products. As the cost driver theory is an indispensable causal foundation for Should Costing in networking products. By determining and quantifying the systematic influences and costs that govern them, from architectural decisions to manufacturing execution, it enables organizations of all types to seek transparent, resilient, and strategically successful cost management. In an era of rapid technological change and supply chain uncertainty, cost driver theory enables Should Costing to resolve challenges that traditional cost approaches cannot address (Kalir, 2023; Jiang et al., 2022).

2.3 Design Structure Matrix (DSM) Driven Teardown Theory

Teardown helps with reverse-inferring the architecture. Tear Down analysis has its challenges and for this reason companies are still not widely applying Tear Down

analysis (Ottinger, 1993; Jiang et al., 2022). The review of the academic research literature found gaps, which are very little covered in previous academic research that is focusing on Tear Down analysis. Structure Matrix driven TD is responding to some of the current critical issues (Fine, 1998; Jiang et al., 2022). With the increasing complexity of networking applications, in which they now require a convergence of high-speed digital logic and analog/RF subsystems, optical engines, and a set of programmable hardware to drive cost and performance, conventional price estimation and analysis can prove inadequate to accommodate the ever complex dynamics driving cost and performance.

Design Structure Matrix (DSM)-Driven Teardown Theory combines system architecture analysis with real world teardown insights to explore hidden cost drivers in closely connected product systems as a whole form a structured analytical framework. Within the umbrella of should costing, which aims to estimate product costs under high engineering and manufacturing efficiency, DSM-Driven Teardown Theory provides two critical skills: (1) systematic mapping of interdependencies among product components and processes, and (2) causal interpretation of cost implications resulting from architectural complexity (Yang et al., 2023). This section builds a thorough theoretical exposition of DSM-Driven Teardown Theory and explains why it is needed for networking products and reveals how its applications respond to current challenges in should costing. The Design Structure Matrix (DSM) is a compact representation of a system's architecture in which elements (e.g., components, functions, processes) and their interactions are arranged in a square matrix to capture dependencies and information flow (Steward, 1981).

A DSM may be based on a physical product structure, functional interactions or process sequences. The primary theoretical concept is that structural dependencies impact

complexity, coordination, rework loops, and ultimately on cost. The DSM is based on systems engineering theory which stresses that all systems are composed of elements whose interactions make the system behave as it is expected to behave. In other words, the tight coupling between sub-systems of complex products has non-trivial dependency patterns that contribute to increased testing needs, defect propagation and the problem of modular decomposition, all factors with cost consequences that cannot be averaged out (Baldwin and Clark, 2000).

Product Teardown is a physical disassembly of a specific product to expose what products it contains, if that product can be physically dismantled or reused. In cost management and competitive benchmarks, teardown adds empirical cost visibility by showing part counts, sources of suppliers, technology selections and design decisions that determine cost (Otto and Wood, 2001). But in isolation, teardown is descriptive, listing aspects and assembly steps but not disclosing an architecture-dependent interdependency that describes how alterations in one part impact the others. Overlooking interdependencies could result in cost estimators misestimating the cost impact or failing to analyse structural cost drivers. A merger of these two approaches, DSM-Driven Teardown Theory contextualises teardown insights within a dependency framework which can explain how and why cost drivers arise from architectural complexity and from process interactions. One Unified Analytical Framework was DSM-Driven Teardown Theory, which combines Architecture and Cost Insight issues (Zhang and Li, 2025; Debnath et al., 2025). So, at the core of DSM-Driven Teardown Theory is the idea that cost is created, not via separate components, but interactions between components. Among networking products, like high-throughput routers, optical transport equipment or modular switch chassis, component interdependencies exist over multiple realms: Electrical dependencies, such as signal integrity paths over multiple different boards,

Thermal and mechanical dependencies, such as heat dissipation networks across modules, Protocol and timing dependencies, such as synchronization across distributed processing units. A DSM of these dependencies allows cost analysts to locate clusters of interdependent parts which are centralized with regard to design and manufacturing complexity. These clusters are those of high coordination cost (in design, assembly and test) which tend to be significant sources of total cost. A networking product DSM would look something like Rows and Columns for components (ASICs, PCBs, optical modules, power subsystems); Cells for dependency strength; signals, mechanical interfaces, shared services (for example, clocking) (Kalir, 2023; Jiang et al., 2022).

Process DSMs capturing manufacturing and test sequences with feedback loops (rework loops), cycle time dependencies, and parallelisation potential. By mapping together physical teardown data as well as other metrics on top of the DSM, analysts can now quantify Functional density — how many dependent interactions a component participates in, Coupling strength — how closely the behavior of a component is reliant on interactions between other parts, Coordination cost — the expected overhead due to dependencies in assembly, testing and rework (Kalir, 2023; Jiang et al., 2022). This facilitates the development of cost models that can account for interaction costs—a departure from traditional bottom-up cost estimates, which only account for part count and material cost. We have seen how DSM-Driven Teardown Theory can help address various issues in Should Costing.

A big issue: Hidden Architectural Complexity, in which traditional should costing approaches usually start with a parts list from a bill of materials (BOM) or teardown (Longauer et al., 2024). Of course, in the world of networking products architectural complexity is inbuilt into the interactions between components not captured by even a basic BOM. For example, a 100-Gb/s optical line card may include multi-layer PCBs

with high-speed differential pairs, electrical-optical interface modules with very accurate alignment tolerances for interfacing, ASICs with built-in SerDes channels which must interact multi-dimensionally. A DSM demonstrates that the cost dimensions of these interactions—e.g., signal integrity, cooling, board stacking, etc.—cannot be addressed individually. DSM-Driven Teardown enables cost drivers to be associated with system-level dependency patterns, thereby reducing the variance in cost estimates that are too high for true technological complexity (Longauer et al., 2024). Supplier Opacity and Information Asymmetry is another challenge when suppliers of specialised components (e.g., custom ASICs, optical engines) frequently hold detailed internal knowledge of internal design and processes. Traditional cost estimates suffer from information asymmetry, as the supplier has so much more information about the cost of the manufacturing as a whole and can know so much more than the buyer can (Kalir, 2023; Jiang et al., 2022). The DSM-Driven Teardown Theory addresses this asymmetry by using observable dependency patterns (such as wiring, signal paths) to deduce process complexity using DSM clusters to predict components that will cause yield loss or rework cost, mapping dependency patterns to known manufacturing constraints (e.g., high speed of signal layers needing additional test cycles). Essentially, DSM assists in transforming structural observables into analytic inferences about cost drivers, when suppliers are not directly implicated and direct disclosure of price drivers is not required. Another issue discussed in previous section is a third kind, that of Rapid Technological change mentioned above. Fast emerging networking technologies are also changing with every change in the cost terrain (400G → 800G → 1.6T interfaces, et al.), which also change the cost curve. Traditional lying static BOM based cost models cannot cope up with changes in physical and protocol complexity. DSM-Driven analysis, by contrast, is design-centric from an architecture point of view.

With the arrival of new activities (new SerDes lanes, higher standard modulation formats) the ways in which interdependencies are affected can be assessed based on revisions in DSM analysis and recalculations of cluster costs. This leads to a dynamic should costing, that updates with the technology. The assembly and testing dynamics is another problem issues (Zhang and Li, 2025). In the realm of high performance networking hardware, production costs are frequently higher than material costs due to tight tolerances, high rework feasibility and extensive functional and performance testing. DSM process models capture rework loops, feedback mechanisms, and parallelisation opportunities in manufacturing. By mapping where these loops occur (e.g., if they fail the test or rework many dependent modules) DSM-Driven cost analysis allocates cost premiums to areas of high rework risk—something a stand-alone teardown or BOM cannot do issues (Zhang and Li, 2025).

DSM-Driven Cost Modelling Methodology and Application DSM-Driven Cost Modeling approach includes developing the DSM for a Networked Product. From the implementation, the steps are as-so component identification through teardown, dependency definition (electrical, mechanical, thermal, data), matrix building based on weighted dependencies. It is also cluster analysis, where the researchers use algorithmic partitioning to find the modules that are highly coupled, and the cost drivers mapping to the dependent clusters i.e. relate the dependency clusters from known cost phenomena (e.g., yield, test complexity, rework loops). For instance, the cluster could cluster high-speed ASIC, combined clock distribution, and power subsystem components as a high coordination cluster with a specific cost premium on it due to complex test and assembly need. Once DSM clusters are identified material cost estimates start from component valuation: Interaction cost is a function of the density and weight of DSM clusters.

Process execution expense (e.g., rework iterations, test cycles) is estimated from DSM process loops. Thus, should cost models be multi-dimensional, including parts cost and architectural complexity cost. DSM-Driven Teardown Theory adds further theoretical theory to this study by taking systems engineering theories to cost driver analysis, where architectural dependencies are revealed as the first order cost drivers in networking products, showing that teardown data have explanatory power of being contextualized in a relational dependency framework. Also, this theory provides opportunities for empirical work that can test dependency-based cost premiums and understand how DSM patterns explain manufacturing outcomes (yield, cycle time and total cost). Thus, DSM-Driven Teardown Theory allows us a theoretical path to analyzing cost in networking products and connects architectural dependencies to the teardown perspective. This will equip costing to tackle obscured complexity; supplier opaqueness; fast-paced technology evolution and complex assembly/test dynamics — all elements that traditional bottom-up or BOM-specific approaches are inadequate to resolve.

2.4 Summary

Through the literature review a clear understanding on key trends and perspectives in Should Costing and Teardown Analysis. The literature review helped in studying about where SC and TD has arrived as of today. It also given lights to next step advancements in SC and TD as listed below!

Formalizing teardown as a “knowledge-generation / design-learning” method for designers, RandD, innovation, beyond reverse-engineering (Otto and Wood, 2001). Hierarchical Cost Breakdown Structure (CBS) linked to function and architecture. CBS derived from Teardown Bill of Materials, dynamic CBS for iterative design changes. Process-Based Cost Modeling (PBCM) enables highly defensible cost estimates for

PCBs, ASICs, mechanical housings, Thermal components, High-volume manufacturing lines (e.g., routers, IoT, telecom gear) (Otto and Wood, 2001).

"Bottom-Up vs. Top-Down Should Costing is trending towards Hybrid Approach. Use top-down to set boundaries; bottom-up for accuracy. Parametric Cost Modeling using ML-based parametric models using manufacturing datasets. Supplier Economics and Should-Cost frameworks link supplier economics to global value-chain models, currency fluctuation scenarios, learning-curve effects (Boothroyd et al., 2011).

Modern Design-for-Cost (DfC) includes Design for supply-chain resiliency, Design for circularity and recycling, Cost-aware generative design (AI) (Ulrich and Eppinger, 2016).

AI-Augmented Should Costing (Emerging): Vision-based BOM extraction from teardown images, ML-based prediction of manufacturing process parameters, automated CBS generation from CAD / STEP (Mechanical design) files (Ulrich and Eppinger, 2016).

From 1st set of the literatures reviewed it's clear that industry has progressed a lot on "SC" and "TD". The papers (Kalir, 2023; Jiang et al., 2022) clearly indicated about evolution of SC models and TD methods, still there are multiple challenges due to which a very common industry adoption is not yet real (Kalir, 2023; Meyer and Zhou, 2024). Examples of reasons for not such wider implementation include cost models dependency on data from very different sources – Bill of Materials (BOMs), Computer Aided Design (CAD) drawings, Enterprise Resource Planning (ERP) tool, supplier quotes, manufacturing process data - and these are often not well integrated (Kalir, 2023 ; Jiang et al., 2022). Inaccurate or Incomplete Data is another issue which leads to incomplete analysis and thus is not as productive as expected (Rao et al., 2024). Another challenge is how to ensure supplier Collaboration and Trust -- Suppliers may push back on should-cost models, especially when the buyer uses them as a negotiation weapon. Justifying

Assumptions, Validation and Credibility, Complex Assumptions and Risks of misuse found to be other challenges which couldn't see the existing research addressing (Ottinger, 1993; Wright, 1936).

Likewise in TD as well as challenges were clearly identified with respect to addressing Advanced Packaging Complexity – Integration of multi-functions under single package, fan-out packaging, multi-die stacks, advanced packaging materials, thinness of silicon substrates and fragile structures making TD difficult (Berk, 2010). Tooling and Resource Constraints is another challenge where specialized tools: X-ray microscopes, SEM (scanning electron microscopes), FIB (focused ion beam), etc are required. These are expensive and need expert operators. Skilled personnel -- Multidisciplinary teams are required (mechanical, materials, electrical, failure analysis (Cescon, 2019).

From the 2nd set of literature reviewed, it was clear that a very few academic papers attempt (Berk, 2010; Rao et al., 2024) a full “bottom-up should-cost” model covering all cost elements (fab Operating Expenses (OPEX), Capital Expenses (CAPEX), test, packaging, yield, scrap, etc.). Thus, an End-to-End approach on SC and TD found to be missing in the papers reviewed! While some papers (Ottinger, 1993; Jiang et al., 2022; Sandborn et al., 2006) look at carbon/emissions, there's less work on integrating operational cost, environmental cost, and regulation cost into unified should-cost frameworks.

Not many studies (Ottinger, 1993; Jiang et al., 2022; Sandborn et al., 2006) have been done on how to effectively utilize AI/ML for Cost Modeling. No papers were spot that addressed how should costing be used as driver for Make-or-Buy Decision making. Very limited studies (Ottinger, 1993; Jiang et al., 2022; Sandborn et al., 2006) on how to benchmark and validate the SC outcome arrived at. Most importantly, effective ways of supplier collaboration: Not many papers talk about how the SC could be used as a win-

win liver so that supplier resistance could be minimized, and all effectiveness could still be realized (Chen et al., 2021). Most importantly many of the critical challenges are not touched in any of these research papers (Varadarajan, 2013) and are thus staying as roadblocks to the widespread use of SC and TD!

To conclude with this research I intend to demonstrate that SC and TD are very much value adding techniques to Networking Industry. Even though there are challenges where industry is stuck or thus the usages of such techniques are limited, this study is intended to give clarity on some of those and provide incremental approaches to tackling such challenges! Through literature review, I could arrive at two main theories which can potentially provide solutions to some of the challenges Should Costing and Tear Down. These theories are “Cost Driver Theory in Should Costing” and “Design Structure Matrix (DSM) Driver Teardown Theory”. Thus the intention of this research work by me is to apply these two theories and find solutions to major challenges in Should Costing and Tear Down Analysis.

CHAPTER III: METHODOLOGY

3.1 Overview of the Research Problem

Despite substantial theoretical and methodological advances in Should Costing (SC) and teardown (TD) analysis, the networking hardware industry, encompassing routers, switches, line cards, and optical transceivers, continues to rely predominantly on supplier quotations, historical cost baselines, and ex-post financial controls rather than analytically derived cost benchmarks (Cooper and Kaplan, 1988; Shank and Govindarajan, 1993).

This practice persists even though networking products are characterised by high material cost intensity, modular architectures, rapid technology evolution, and compressed product life cycles, conditions under which should-costing and teardown-based approaches are theoretically well suited (Lee and Park, 2024; Fine, 1998).

Classical should-costing and cost driver theories emphasise the decomposition of products and processes to identify the fundamental determinants of cost, including material content, manufacturing processes, scale effects, and organisational learning (Wright, 1936; Riley, 1987; Argote and Epple, 1990). Teardown analysis has been shown to potentially lead to effective implementations of these theories by reconstructing cost structures through systematic product disassembly and benchmarking (Ottinger, 1993; Sandborn et al., 2010). Nevertheless, based on the empirical observations, traditional teardown approaches seem to often be static and concerned with components and mainly concentrate on bill-of-materials reconstruction that fail to take yield losses, test complexity issues, reliability issues, rework, and system integration costs into account (Sandborn et al., 2006; Jiang et al., 2022). Indeed, for example, in the networking sector, it is the scaling of semiconductors, large-scale integration of advanced optics systems and firmware dependence which also leads to high system integration costs and a platform reuse of products, that make up a major risk factor that is under-represented in a typical

costing model (Fine, 1998 ; López and Díaz, 2024). Modularity theory argues architectural decomposition to gain cost transparency and attribution. In practical terms, modular networking systems hide cost drivers in the supplier-specific process capabilities and learning curves, therefore making teardown-based estimates less accurate, repeatable, and credible (Lee and Park, 2024; Longauer et al., 2024). The literature very evidently shows that industry practices have seen a dramatic development in evolution of Supply Chain (SC) and Technology Development (TD) methodologies. Theoretical advances have seen should-cost models for doing so, techniques and teardown (Markandya, 2000) have been reported extensively but they remain underexplored and still, this method to do so has not spread the industry.

Although theories like should costing and teardown analysis are grounded in principles, they are often viewed as being organizationally costly, politically awkward, politically delicate, and strategically dangerous practices, and firms will not integrate using them regularly as traditional decision support tools (Jiang et al., 2022). Hurdles include high implementation costs, limited visibility of principal cost drivers, restrictions on agency capacity, limited organization's free will to perform, strategic price issues, and likelihood for supplier opposition. The main problem identified in the literature is lack of guidance on selecting and applying models. Numerous SC and TD models exist, but it is not always clear which types of product or business apply best (Kolaczinski, 2006; Xu and Yin, 2023). Many of these models have clear technical and methodological problems especially in electronics manufacturing, in which teardown methodologies do not directly record the critical cost factors such as yield loss, rework time, test coverage, learning curve and overhead allocation (Becker et al., 2020).

Should cost models require a variety of data, e.g. bills of materials, CAD data, ERP systems, supplier quotes, and manufacturing process data. These data can, however, be

poorly integrated or incomplete, rendering your analysis less accurate (Kolaczinski, 2006; Liu et al., 2021). A problem that stubbornly won't go away is cost dynamism. The costs of inputs such as raw materials, labor, energy, and logistics (especially in electronics supply chains), all require a considerable amount of adjustments and are quite volatile over time, and static cost models cannot endure without being replaced with new models (e.g., Kolaczinski, 2006; Liu et al., 2021). At the same time, practitioners face a dilemma between making models more detailed or more user-friendly. Granular models can greatly increase accuracy but become complex, difficult to maintain and hard to validate or communicate. Conversely, over-simplified approaches may risk neglecting important cost drivers such as process-specific yield losses and/or complexity of tests (Adam et al., 2003; Ștefea et al., 2008). Therefore, many authors consider that by integrating teardown, parametric modeling, expert judgment and learning curve, hybrid methodologies provide a more appropriate performance as it provides reliable functional relationships among engineering parameters and costs (Korshunov and Petrushevskaya, 2018).

Conventional should-costing techniques also predominantly rely heavily on first-order cost drivers of material, such as weight, machine time, or the quantity of direct labor hours (Fine, 1998; Liu, 2025). Modern cost driver theory now extends this concept to include second-order drivers: such as process complexity, tolerance requirements, manufacturability constraints (DFM/DFA), tooling amortization non-linearities, and third-order drivers: supply-chain resilience, supplier capability maturity, learning curves, volume-risk asymmetry and quality-capability correlations (Korshunov and Petrushevskaya, 2018). These higher-order drivers are highly pronounced in networking products, yet they are weakly accounted for in current Supply Chain (SC) and Technology Development (TD) practice. Theoretically, another limitation relates to the underappreciation of Transaction Cost Economics (TCE) in should-costing models.

Supplier pricing involves not just manufacturing costs but also transaction costs associated with asset specificity, opportunistic behavior, contractual risk, and supplier lock-in (Williamson, 1985). According to Korshunov and Petrushevskaya (2018), classical should-costing models are typically not tailored to these dimensions which significantly lowers their effectiveness for facilitating make-or-buy decisions, outsourcing mechanisms, and contracting frameworks. In terms of organizational risk and return potential, SC and TD projects face high upfront cost with uncertain returns. Teardowns require skilled engineers, specialty laboratories, and lots of time to analyze. By contrast, should-cost models require significant process knowledge and ongoing upgrades. In practice, organizations prefer some form of benchmarking — which gives a rough idea of costs, over analytically correct models that require too much labor (Cooper and Kaplan, 1988).

Studies show low returns from repeated “teardowns”: the first analysis yields great insights, but subsequent teardowns provide very little learning (Cooper and Kaplan, 1991). There are also big issues with organizations and skills that make it more difficult to adopt. Good performance in SC and TD analysis requires a combination of skills in design engineering, manufacturing processes, cost accounting, and supply-chain economics. These skills are often located in various parts of an organization. As a result, companies often outsource teardown jobs or hire consultants only temporarily, making it difficult for them to maintain updated knowledge and models (Cooper and Kaplan, 1991). A limited number of tools and resources complicate that challenge. Many advanced teardowns of modern electronics require specialized equipment (e.g., X-ray imaging, scanning electron microscopy (SEM), and focused ion beam (FIB) systems) and experienced operators (Bengü, 2010). Inference and reverse inference is also at risk: that is, because the same goods may be produced in other factories and/or have different

automation levels or at different stages of maturity. It is thus difficult to use teardown alone to calculate costs (Fine, 1998).

Legal, ethical, and intellectual property issues further complicate systematic teardown programs, particularly as companies deal with jurisdictional boundaries, compliance regulations, and supplier relationships, complicating such systematic teardown programs even more (Porter, 1985), given that they have to navigate regulations related to local jurisdiction or regulatory compliance, and supplier relationships (Porter, 1985). Another barrier there is trusting and working together with suppliers. Using too much should-cost models in negotiating may generate distrust, defensiveness among suppliers, cease new idea sharing, or even provoke suppliers to exit (Riley, 1987). In addition, the challenge of proving assumptions and building up model trust persists to be even more pronounced when complex cost drivers are not easily seen and ascertainable (Ottinger, 1993).

It is becoming more and more challenging to analyze the teardown due to higher complexity in packaging like multi-die integration, fan-out packaging, fragile substrates, and heterogeneity of materials, making it difficult to take apart properly and to make accurate predictions (Bengü, 2010). The advent of software-defined value creation adds to the complexity of cost analysis, since tangible teardown cannot keep up with the increasing price tag and value added by firmware, algorithms, and embedded software (Shehab and Abdalla, 2002). Whether costing and teardown analysis are applicable in certain sectors (automotive, aerospace, defense, high-volume electronics) is unclear but they are mostly used for networking equipment as guidelines instead of as a specific tool for pricing or design decisions (Shank and Govindarajan, 1993). This selective adoption reveals some longstanding gaps between theory and application, with analytically-advanced models, like activity-based costing and time-driven activity-based costing, largely unexplored in practice due to data needs, confidentiality issues, lack of expertise,

and fear of credibility and ROI (Cooper and Kaplan, 1991; Kaplan and Anderson, 2004; Cescon, 2019; Varadarajan, 2013). Therefore the current approaches don't effectively assist to make the cost-performance tradeoff, supplier negotiation, and architectural decisions for the more complex networking products (which are subsystems that are intensively employed in semiconductors and optics). This reveals a major research gap: the absence of a specific, theory-rich, and empirically validated framework for cost estimation and teardown analysis that covers product architecture, manufacturing processes, learning effects, transaction costs, end-to-end constraints in relation to the networking hardware lifecycle. The focus of the present research is to fill this gap.

3.2 Operationalization of Theoretical Constructs

Operationalization — the crucial process in transforming abstract theoretical concepts into operationalized, measurable and observable variables that stand the test of empirical inquiry. In this paper, the main focus of operationalization is connected to the theoretical context of the models should costing, cost driver theory, teardown analysis, and design structure matrix (DSM) theory in relation to the application to networking products like routers, switches, line cards, and optical transceivers in the context of this research. Previous work points to a long-established divide between theoretically sound cost estimation frameworks and its relevance to the real-world, particularly under high-complexity, modular and rapidly evolving technical environments (Cooper and Kaplan, 1991; Sandborn et al., 2010; Jiang et al., 2022). This research addresses this issue by empirically defining essential constructs that allow for systematic investigation, repeatability and validation in the networking hardware sector. From the research problem and literature synthesis, we can distinguish and discuss the different relevant theoretical constructs such as should cost accuracy, cost driver visibility, teardown granularity, product architecture dependency, process and yield complexity, learning and

scale effects, transaction cost factors, DSM-based architectural coupling and organizational feasibility of should costing. Underpinning the theoretical framework of each construct is already established theory and manifested by observable indicators applicable to such products on network.

The operationalization of Should Costing Constructs

According to Should Costing Theory while estimating costs, accuracy is defined as the extent to which analytically estimated costs are close to the economically efficient cost of production in a practical context (Angelis and Nussbaum, 2015). Cost accuracy in this context may be described as the difference between estimated should cost and validated reference cost, where reference cost terms could represent supplier disclosed costs (when possible), benchmark teardown studies and long term negotiated, volume and learning adjusted price. Indicators of measurement are the absolute percent error between should cost estimate and benchmark cost, cost variation by subsystem (PCB, optics, ASIC, power), and how consistent estimates are after re-teardown. Such operation can be an assessment of whether DSM based teardown and cost driver theory enhances the estimation (dependence and accuracy of the estimate) to bimodal estimation compared to conventional BOM models (Sandborn et al., 2010; Becker et al., 2020). Should Costing Needs to see what the cost driver cost drivers are doing. Cost driver theory suggests that the behavior of costs occurs as a consequence of not only first-order drivers (the amount of materials and labor time), but also among higher-order drivers, including other factors, such as complexity, learning, and organizational capability (Riley, 1987; Korshunov and Petrushevskaya, 2018).

Cost driver visibility is the degree to which the relevant cost drivers are given the explicit recognition, quantity of cost drivers and how they relate to the cost outcomes, in the should-cost model. Measurement will be by identifying how many direct (i.e., explicitly

modeled) cost drivers are modeled (i.e., first, second, third-order cost drivers and number), by the existence of process-based and architecture-based drivers, and by tracking each cost driver to an attribute such as physical, process or architectural attribute. The drivers in networking products are the PCB layer count, optical alignment tolerance, ASIC die size, firmware test coverage to platform reuse, etc (Roberts and Ahmed, 2022; López and Díaz, 2024). Another conceptual model being considered throughout this paper is Teardown Granularity.

Classical teaching methods of teardown focus on the breakdown level of components of models without much to offer in terms of system interactions and process links (Ottinger, 1993; Sandborn et al., 2006). Its operational definition is teardown granularity is operationalized as the extent and breadth of decomposition achieved in the course of product disassembly and analysis. Indicators in the method are degradations (system → module → sub-module → component → process step), inclusion of manufacture and testing processes deduced based on teardown, yield sensitive and reliability critical elements. Higher granularity also helps to reflect these non-BOM cost drivers (e.g. likelihood of rework, test complexity, thermal-mechanical constraints) which is a primary concern for sensitive optics- and semiconductor-based networking hardware (Bengü, 2010). We will now turn to Process and Yield Complexity construct. Theories from manufacturing theory and the learning curve literature suggest that yield losses, rework and process maturity have been identified as the primary contributors to costs in advanced electronics manufacturing, particularly for electronics fabrication (Debnath et al., 2025).

Process and yield complexity is operationalized as how cost is related to the level of sensitivity of cost to manufacturing variance and test results. Measurement consists of yield loss estimates per process step, test coverage complexity (number of test stages,

time per test), and rework probability estimated using design and assembly characteristics. This concept alleviates a significant limitation of static teardown models observed in previous works (Sandborn et al., 2006; Liu, 2025). The key theoretical construct was Product Architecture Dependency. Modularity and architectural theory posit that cost behavior is constrained by system interdependence of elements (Gupta and Sharma, 2022).

Dependency in product architecture is defined by its level of coupling with components, modules and subsystems in the DSM. Indicators of measured interdependencies are the number and strength of interdependencies in the modules, the identification of cost critical architectural bottlenecks and a shared component, and platform reuse mapping. Networking products often have hidden coupling between optics, ASICs, thermal design and firmware, which is not captured by conventional costing techniques (Fixson, 2005). DSM-Based Cost Driver Propagation: DSM theory provides the foundation for modeling how variations in one component propagate throughout the system (Eppinger and Browning, 2012).

DSM-based cost driver propagation is explained by the degree of the impact of cost in one module on other modules through architectural dependencies.

Measurement indicators are cost sensitivity matrices derived from DSM, identification of leverage points where small design changes drive large cost effects and comparison of DSM-informed vs non-DSM cost estimates. This operationalization directly addresses the research gap related to architecture-driven, non-linear cost behavior in networking systems.

Learning and Scale Effects is a key one! Learning curve theory predicts systematic cost reduction with cumulative production (Wright, 1936; Argote and Epple, 1990). Learning effects are operationalized as the rate of cost reduction per doubling of cumulative

volume, applied selectively to processes with demonstrated learning sensitivity.

Measurement indicators include learning curve slope assumptions by process, volume-dependent cost scenarios and sensitivity of should cost to production scale.

Transaction Cost Factors emphasizes that supplier pricing reflects governance costs, risk, and opportunism in addition to production cost (Williamson, 1985). Transaction cost factors are operationalized as qualitative and semi-quantitative adjustments to should cost estimates reflecting supplier behavior and contracting context. Measurement indicators include supplier concentration and switching cost, contract type (fixed-price vs cost-plus) and supplier capability maturity and learning position. This extends traditional should costing beyond purely technical cost estimation (Korshunov and Petrushevskaya, 2018).

Organizational Feasibility Construct: Management accounting literature highlights organizational capability as a determinant of method adoption (Cooper and Kaplan, 1991). Operational definition is Organizational feasibility is operationalized as the ability of the firm to sustain should-costing and teardown practices over time. Measurement indicators are availability of cross-functional expertise, tooling and data integration maturity and frequency and continuity of teardown application.

As a conclusion, through this operationalization, the research establishes a mapping between theory and empirical analysis. DSM-driven teardown enhances cost driver visibility, which improves should cost accuracy, while accounting for architectural coupling, learning effects, and transaction costs. This integrated operational framework enables systematic evaluation of how theoretical advances can resolve practical challenges in should costing for networking products.

3.3 Research Purpose and Questions

The purpose of the research is to use the already existing developments, and available research works to arrive at an effective Should Costing and Tear Down Analysis process

including tool and method recommendations to perform Should Costing and Tear Down analysis on products used in modern Communication Networking. The products in Networking comprise of assembled subcomponents as well, the intended scope application includes them too. Examples of such assembled subcomponents are Power Supply Units (PSUs), Pluggable Optical Transceivers, Cable Assemblies, etc. As indicated previously in this document, various challenges in Should Costing and Tear Down is blocking the frequent use of these in Networking Industry. The idea from this research is to provide as much incremental help to enable more frequent application of Should Costing and Tear Down as an information gathering, benchmarking and continuous learning system for new Designs as well as a collaborative lever for cost discussions with key vendors and partners.

Also, the objective of the current study is to provide a comprehensive review of literature and industry practices in relation to Should Costing and Tear Down Analysis and outline a conceptual framework for these. To achieve the above purpose, this research is guided by the following questions. RQ = Research Question.

RQ1: What are the Should Costing and Tear Down techniques/methods available today in Networking Industry? What are their advantages and disadvantages?

RQ2: How can teardown analysis be systematically used to identify and quantify key cost drivers in networking products?

RQ3: What are the most appropriate tools and methods on Should Costing and Tear Down suitable to products in Networking Industry, that provides incremental solutions to some of today's challenges in Should Costing and Tear Down?

RQ4: What methods could be adopted to address the high upfront cost and diminishing returns of Should Costing and Tear Down? Any incremental solutions possible here?

How to overcome the Organization Capability Barriers that impede the frequent application of Should Costing and Tear Down.

RQ5: To arrive at methods to handle the issue of Reverse Referencing Risk (RRR), which is about wrong assumptions by Should Costing/Tear Down team about same/similar product is equal to same manufacturing process (Longauer et al., 2024). Define as to in which cases this policy of “same process” applies vs which cases it needs reassessment to find out the manufacturing process.

RQ6: What are the legal, ethical and IP concerns while doing Should Costing and Tear Down?

RQ7: How Should Costing and Tear Down could be effectively utilized in supplier collaboration as opposed to supplier push backs and stiffening relationships, which is at present one of the biggest challenges (Longauer et al., 2024) in wider adoption of Should Costing and Tear Down techniques in Networking industry?

3.4 Research Design

This study takes a design-oriented and empirical research approach, which is based on theoretical development and applied industrial research. The research design is predominantly qualitative–quantitative in character, as established theories of should costing, cost driver analysis, and design structure matrix (DSM) are inductively aggregated and implemented through the application of networking hardware case studies. Due to the divide between theoretical costing models and their implementation in practice in the networking industry, the research adopts an exploratory–explanatory design. The exploratory component focuses on the existing limitations of should costing and teardown practices, while the explanatory part analyzes the potential for DSM-based teardown and extended cost driver theory to overcome these. This study employs literature review as the principal research strategy. This approach is justified as

networking devices (routers, switches, line cards, optical transceivers) are complex systems in which the behavior of costs is affected by architecture, process interactions, and supplier-specific variables. The primary research method employed in this study is a systematic literature review, as the first step of knowledge acquisition about should costing and teardown analysis. Based on reviews of academic journals, industry reports, conference papers, and published books, the review looks at the past and present of should costing and teardown processes. This review provides a basis for the selection and consolidation of the relevant theoretical perspectives, practical applications, and enduring obstacles hindering the broad and regular implementation of these techniques in industry. The literature review is performed in two stages. First, it considers should costing and teardown analysis in general and across sectors. Second, it focuses on networking products and subassemblies, with special attention to specific cost structures, architectural difficulties, and the accelerated technology development of networking equipment related to the different cost structures, architectural complexity, and rapidity of technology of building hardware. A consolidated set of challenges and limitations related to current should costing and teardown practices is established based on insights from the literature. The case study approach is adopted in the study for the purpose of complementing findings based on literature and to present empirical evidence. This review is focused on limited case studies from networking products, emphasizing subassemblies typically explored within industry, for instance, power supply units and pluggable optical transceivers.

The assemblies such as the ones listed above are selected for their high material cost element, supplier dependence, and applicability to the procurement and cost negotiation processes of the networking sector. The research strategy includes couple of should costing case studies and couple of teardown analysis case studies that makes it possible to

focus on a deep-dive analysis of both approaches. The study also provides semi-structured expert interviews for practitioner viewpoints and current industrial practice. Interviews are performed with key functional stakeholders in the design, engineering, manufacturing, and procurement of networking products. It was the market leader in the networking industry where this researcher was, and an expert or specialist from each respective function (design, engineering, procurement) was interviewed for this analysis. For external validity and to avoid organisational biases, the researcher gets interviews from equivalent professionals from a top-performing networking company outside the organisation of the researcher. The results derived from these interviews are utilized to:

- Knowledge of current industrial practices and expectations with regards to should costing and teardown analysis.
- Recognize practical challenges that academic literature fails to adequately cover.
- Evidence hypotheses and conclusions expressed by the literature review and case studies.

Additionally, the research is a comparative study between current cost models, examining the pros and cons, data needs, and relevance to networking products. The practitioner's professional background of should costing and teardown analysis is harnessed for the critical analysis of these models, and to situate insights gained from literature and empirical work. This empirical context ensures further understanding of emerging findings, as well as an applicable and feasible framework. The integrated results of the literature review, case description, expert interviews, and modelling underpin this paper's proposed end-to-end should costing and teardown process model at the networking hardware industry level. The following approaches are used in the study.

- Systematic literature review.

- Expert interviews (design, engineering, manufacturing, procurement).
- Case study of networking products and subassemblies.
- Comparative evaluation of existing cost models.

3.5 Population and Sample

As indicated above primarily the study concentrated in going through a variety of literatures selected from Should Costing and Tear Down analysis domain within and outside Networking Industry. The population for this study comprises networking hardware products and industry professionals involved in cost-related decision-making within the networking equipment industry. At the product level, the population includes networking systems and sub-assemblies such as routers, switches, line cards, power supply units, and pluggable optical transceivers, which are commonly subject to should costing and teardown analysis in industrial practice.

At the human and organisational level, the population includes industry professionals who are directly involved in the design, engineering, manufacturing, procurement, and cost management of networking products. These individuals possess domain-specific knowledge related to product architecture, manufacturing processes, supplier interactions, and cost estimation practices, making them appropriate informants for understanding the practical challenges and limitations of should costing and teardown analysis.

A purposive, non-probability sampling strategy is employed, as the research requires in-depth insights from knowledgeable practitioners and technically relevant product samples rather than statistically representative samples. From the broader population of networking products, a small number of representative case study samples are selected based on the following criteria,

- High material and component cost content,
- Strong supplier dependency and procurement relevance,

- Architectural and process complexity typical of networking hardware,
- Common use of should costing and teardown analysis in industry.

Based on these criteria, selected sub-assemblies such as power supply units and pluggable optical transceivers are used as case study samples. The study includes:

- One case study focused on should costing, and
- One case study focused on teardown analysis, allowing for focused and detailed examination of both methods within a networking industry context.

For the qualitative component, a targeted sample of industry experts is selected from both within and outside the researcher's organisation. Internal sample include one expert or specialist each from the design, engineering, and procurement functions within the researcher's organisation, which is a market-leading firm in the networking industry. External sample include one expert or specialist from each of the same functional areas design, engineering, and procurement, selected from a leading organisation within the networking industry outside the researcher's organisation.

This results in a balanced expert sample that captures both internal organisational practices and broader industry perspectives, while maintaining focus on domain-specific expertise.

3.6 Participant Selection

The selection of participants for this study is based on purposive sampling methods appropriate for studies that necessitate specific knowledge of multiple subjects, as opposed to high-level statistical modeling. The aim of the selection of participants is to bring insight from people who are exposed to, or have had extensive working, experience with should costing, teardown analysis, product design, fabrication and procurement procedures in the networking hardware sector. For External participants, the criteria used to select participants are as follow:

- Involvement of the development, engineering, manufacturing and purchasing of networking products.
- Professions relevant such as estimates of the costs of items, contracts and projects - if any - to be acquired and also experience in supplier negotiations or cost reduction solutions, including should costing or doing teardown analysis.
- Some degree of professional exposure that allows for the production of sound and reflective comments on cost structures, procedures and organisational procedure.
- Working in firms in the networking equipment industry, for complex, hardware heavy products.
- These criteria assess whether participants have both the technical and managerial skills needed so that they contribute in a meaningful way to addressing, and achieving, the research aims.

In terms of Internal Participant Selection, in my company that is a market leader in the networking industry, we will include a list of participants from the key functional areas in the organisation that influence costs. These areas include Design, Engineering / Manufacturing Engineering and Procurement / Commodity Management. Based on relevance and experience, one expert or specialist is appointed per function. Participants are also expected to bring some valuable information about company-specific processes, cost modeling behaviours, design–cost trade-offs, and organisational limitations concerning should costing and teardown analysis. This double-process selection approach minimises the single-firm bias and enables us to separate the industry-based challenges from organisational-specific dilemmas. Respondents are to be selected from work sources, company directories and references from executive management. Formal contact commences with communication explaining the purpose of the study, the level of participation expected, and assurances about confidentiality. Involvement is voluntary,

and obtaining informed consent before conducting interviews. There is a fairly small, focused group of participants included in the study, which complies with qualitative research and case study methodologies. The number of participants selected is adequate to address a range of the functional perspectives around should costing and teardown analysis and the identification of common patterns and challenges across roles and organisations, help triangulation with insights from literature reviews and case studies. Instead of a numeric representation, there is this attention paid to depth, expertise, and significance. Ethical implications are prioritized in the process of research. All participants are notified that the research is of an academic nature and that no proprietary or confidential information is needed. Personas of participants and organisational affiliations are anonymised throughout all publications and reports. The data collected from interviews is for research purposes only and is stored per ethical research guidelines. To sum up, the purpose of participant selection in this study is to have well-experienced professionals in key functional regions in the networking hardware industry. This methodology guarantees that the research gains rich, practice-sensitive knowledge that pertains to assessing and progressing should costing and teardown analysis methodologies in a complex industrial world.

3.7 Instrumentation

Instrumentation in this study refer to the tools, protocols and analysis tools used to study should costing and the teardown of networking products. In light of the exploratory and applied nature, some qualitative and analytic methods are used to monitor methodological quality, consistency, and replicability of the methods. This article is based on a literature review methodology which was systematically reviewed as the main tool in identifying, selecting and analysing relevant academic and industrial sources. The protocol includes well-articulated search terms for should costing, teardown analysis, cost driver theory and

networking hardware, selection criteria for relevance, integrity and date of research as well as systematic extraction of themes, challenges and methodological perspectives. The instrument for the literature review facilitates identification of theoretical constructs, gaps, and industry-related issues which are used to frame the research.

Case Study and Teardown Instruments

For the empirical part, the teardown analysis templates and the documentation checklist were integrated to provide consistency into case studies. These instruments also inform the systematic disassembly and analysis of some networking sub-assemblies (e.g. power supply units and pluggable optical transceivers). Several essential aspects captured in teardown instruments were component identification and classification, material content and packaging properties, assembly complexity and inferred manufacturing processes, and interface and dependency observations pertinent to DSM modeling. Photographs, structured teardown logs, and component maps are all used to capture results and provide a back-to-back relationship between physical evidence and cost modeling constructs. Should Cost Modeling Instruments also be used. Should costing is backed by formal cost modelling templates designed to model first-, second- and selected third-order pricing drivers. These templates document Bill of materials and material cost assumptions, process steps, cycle times, yield assumptions, overhead and learning curve considerations, as well as any supplier and transaction cost adjustments if any. Spreadsheet-based cost models are used as the main analytic tool owing to its transparency, flexibility and applicability for use in scenario and sensitivity analyses.

Interview Instruments used are semi-structured interview guides that are the main instrument that were utilized for gathering expert views from participants in design, engineering and procurement. The interview guides feature open ended probing questions

that address current practice of should costing and teardown, perceived limitations and challenges of doing so, availability and the constraints associated with the accessibility and the organisational capacity to provide data, perspectives on architectural complexity and cost drivers. The semi-structured structure maintains consistency between interviews but also allows for open-ended interviews examining perspectives relevant to the function. Interview notes and audio recordings, when possible, are employed for more precise data collection. Responsible use of Ethical and Data Management Instruments is done when research work. Participant consent forms, anonymisation protocols, and safe storage practices with secure storage guidelines are included to ensure that confidentiality of participants is preserved and ethical research norms are used. All instruments should be used only to avoid any types of proprietary/confidential data collection. In short, this study uses a well-chosen framework of tools such as literature reviews, teardown templates, cost modeling tools, DSM matrices and interview guides to systematically explore should costing and teardown analysis in the networking items. The combined use of these instruments promotes consistency between data sources, fosters triangulation and enhances the validity of the research results.

3.8 Data Collection Procedures

In addition, the data collection technique used in these studies is systemic and multistage, with a view to the reliability of methodology, transparency, and triangulation. The methods combine secondary literature-based data with main data from case studies and case researchers' interviews for a theoretical insight and practice relevance. Literature-Based Data Collection, the initial step of data collection, also entails performing a systematic literature review regarding should costing, teardown analysis, cost driver theory, design structure matrix (DSM) and networking hardware cost structures. Academic papers, conference papers, books, industry reports, and professional charters

are also reviewed to capture both classic and new trends in an area of study. From literature relevant data were collected including definitions and operational models of should costing and teardown analysis, cost drivers and modelling methods, challenges and limitations encountered in the industrial applications, and best practice and methodological variation. It lays the theoretical basis of the study, and it guides the design of the subsequent instruments.

The second stage focuses on empirical data collection using case studies with selected networking product sub-assemblies. All products including power supply units and pluggable optical transceivers are selected based on their cost importance, architectural complexity, and industry practice utility. Case study data is extracted from the physical teardown of selected assemblies through structured teardown protocols; document component composition, material types, package details and assembly specifics; Inference of manufacturing and testing processes derived from design elements and industry norms observed; photographic documentation; teardown logs to ensure traceability and repeatability. The process of teardown is done consistently across cases so as to enable comparison and cross-case analysis. Should cost data be obtained in parallel to teardown procedures using modelling templates in structured form. Data inputs were Bill of materials based on teardown and documentation, publicly accessible material price benchmarks; process cost estimates derived from literature and industry standards; Yield, learning curve and overhead assumptions based on historical studies and expert judgment. These data is logged methodically in order for it to be known and sensitive analyzed.

Data Collection of Expert Interview Data Collection consists of the next step is the semi-structured interview session with certain professionals who are engineers, design, manufacture, and procurement people from the networking industry. The interviews are

carried out following a priori protocols, while following in the spirit of in-depth talking. Methods for data collection for interview included the provision of informed consent from all interviewers, face-to-face or virtual interviews, conducting interviews with participants from various technical and clinical backgrounds, taking notes of them, and anonymisation of the interviews data to maintain anonymity. Interviews will give an overview of current industry trends, available data, organizational structures, and value perceptions of should costing and teardown analysis. Data obtained from literature, case studies, teardown analysis, and expert interviews are verified against each other by triangulation. We check for consistency and difference among data sources to improve reliability and minimize bias. The analysis uses several data inputs to assess key assumptions and key findings. All data obtained is stored securely and used only for academic research. All proprietary information or sensitive material is excluded from analysis. Participant consent, confidentiality, and data disposal/handling are all ethical guidelines and are followed throughout the entire data collection phase. Overall, the data collected in this study is a systematic, iterative process that combines theory-based insight with empirical considerations. This makes use of a literature review of existing studies and teardown-based case studies, as well as should cost modeling, DSM analysis, and expert interviews to ensure that data is adequately presented and provide a solid basis to analyse should costing and teardown actions in the field of networking hardware.

3.9 Data Analysis

The data analysis in this study follows the structured multi-step review and synthesis process that includes both qualitative and quantitative techniques. Thematic synthesis: in the literature analysis, information about the literature used in the literature review is analyzed. The major concepts, frameworks and findings are coded and synthesized into themes (concepts, frameworks and findings) regarding should costing, teardown analysis,

cost driver theory, DSM, modularity, learning effects, modularization, and transaction cost economics; they become grouped under groupings based on principles to support thematic categories. This analysis allows the identification of common obstacles, methodological challenges and theoretical gaps in the field, limits that guide the research framework and the focus of the research. The results of the literature review are then employed to articulate and revise theoretical constructs, shape case study and interview design, develop the criteria for analysing the existing and hypothetical cost models. In Teardown Analysis data collected from physical teardowns is analysed through structured decomposition and classification. Components and sub-assemblies are categorised by function, material type, manufacturing process, and architectural role. Observed design and assembly features are analysed to infer manufacturing complexity, test requirements, and potential yield sensitivities. Teardown findings are analysed at multiple levels. This analysis supports the identification of both observable and latent cost drivers not captured in traditional bill-of-materials-based costing.

Should Cost Model Analysis wherein Should cost data is analysed by constructing baseline and enhanced cost models. Baseline models rely on traditional first-order cost drivers such as material content and process time. Enhanced models incorporate second- and third-order cost drivers, including process complexity, yield effects, learning curves, and transaction cost considerations.

Comparative analysis is conducted to evaluate differences between baseline and DSM-informed cost estimates, assess the contribution of extended cost drivers to overall cost visibility, examine sensitivity of cost estimates to key assumptions. Sensitivity analysis is applied to critical parameters to assess model robustness and identify high-leverage cost drivers.

Interview Data Analysis included data from expert interviews and is analysed using qualitative content analysis. Findings from interview analysis are compared with literature and case study results to validate interpretations and uncover practice-driven insights.

Interpretation and Synthesis: The final stage of data analysis involves synthesis and interpretation. Results from all analytical stages are integrated to evaluate how the proposed framework addresses the identified research problem. The analysis focuses on explaining how DSM-driven teardown improves cost driver visibility, how extended cost driver theory enhances should cost robustness, under what conditions these approaches are practically feasible in the networking industry.

Overall, data analysis in this research combines qualitative thematic analysis with structured cost modeling and architectural analysis. This integrated approach enables a comprehensive examination of should costing and teardown analysis practices, providing both theoretical insight and practical guidance for cost estimation in complex networking products.

3.10 Research Design Limitations

The research design adopted in this study is suitable for achieving research objectives. However it is necessary to note that there are also serious limitations. Recognising these limitations increases both transparency and rigor—at least for reading results. The research is both a practical approach to informing policymaking

Reliance On Secondary Data Sources: A big part of this research is built on secondary data obtained through literature reviews. But while journals, books and professionals published in peer-review can give beneficial information, they do not address the latest proprietary practices of should costing and teardown analysis practiced by some of the

top network firms. Further disagreements in terminology, assumptions, and methodological rigor from one source to the next are likely to result in inconsistencies.

Limited Access to Proprietary Cost Data: The costing and teardown analysis process inherently incorporate commercially sensitive cost information. This study, however, is based less on actual supplier or internal manufacturing cost data than public cost estimations, process assumptions, and expert judgment, which remain confidential.

Consequently, the absolute cost rates obtained from models can also be different from real-world figures but the relative cost driver and structural insights are not invalidated.

Data Limitation: Only ten or more case based cases were observed in the empirical part of the study for particular sub-assemblies of networking products (such as power supply units and pluggable optical transceivers). Although these assemblies are representative and cost-significant, these conclusions may not necessarily apply across all networking products or across different technology generations.

Interpretation is subjective: Teardown is an interpretive decision process where judgement should always be exercised, especially in regards to the estimation of manufacturing methods, yield impacts, and test needs based on physical observation.

While structured teardown procedures and cross-validation with literature are used, some level of subjective interpretation is required. This may affect the identification and weighting of some cost drivers.

The assumptions in should cost modeling Assumptions of Should cost models in this study is based on assumptions of process efficiency, learning curves, overhead distribution and yield. Though these assumptions are based on literature and expert evidence, they do vary considerably between organizations, geographical locations and vendors. As a result, it makes the models more appropriate for comparative and directional analysis than accurate cost prediction.

DSM representations Limitations: While the Design Structure Matrix (DSM) is an effective method to capture dependencies, DSM model structure reduces complex real-world interactions to binary and weighted relationships. Dynamic interactions, like temporal dependencies and supply chain disruptions, are not well captured by static DSM models. This could compromise the scope of capturing all cost propagation effects.

Interview Sample: The study will use qualified interviews among a very small sample including but not limited to those from design, engineering, manufacturing, and procurement functions. However, such a small sample size and industry focus limit the scope of insights captured, as well as the bias in the sample even though the participants are experienced professionals.

Experience and bias of the researcher: The researcher experience with should costing and teardown analysis in the past will be utilized to inform the design and interpretation of the research. This increases practical relevance, although it might also induce accidental bias in the form of model building and data-analysis. Reflexivity and triangulation are used to minimize this risk, yet unbiased methods are not yet available.

Static Study Analysis: This work mainly applies a static study approach which looks at cost structures and architectures at a moment in time. Given the accelerated technological development of the networking sector—particularly optics and power electronics—it is possible that long-term applicability may be limited. Generalizability: Our qualitative and case studies allow findings to be analytically generalizable, not statistically generalizable.

The findings are aimed at informing theory development and managerial knowledge and are not meant to be used as universal cost benchmarks. These limitations stem mainly from data accessibility constraints, modeling assumptions, and scope of empirical investigation. The limitations, however, overlap with exploratory and theory-building research in industrial cost analysis. We can conclude that the insights obtained provide

valuable insights related to DSM-driven teardown and should costing practices for complicated networking products.

3.11 Conclusion

This chapter has presented a complete and coherent research method in order to solve the research problem of using should costing and teardown analysis on complex networking products. In order to ensure theoretical solidity, empirical validity and feasibility in practice due to the technical and organizational elements related to networking hardware cost analysis the methodological background was well-designed. The chapter opened with a description of the theoretical constructs that support the study, originating from cost driver theory, teardown analysis, and product architecture theory. These constructs offered theoretical constructs with which to think about how cost behaviour in networking products is informed by first-order factors like material, labor, and first-order drivers, as well as higher-order drivers including complexity in processes, architectural interdependencies, learning effects, and supplier capability. These constructs had a direct impact on the generation of the research purpose and research questions related to recognizing current should costing practice shortcomings and how structured teardown and DSM-based approaches can lead to better cost transparency and improved decision support. The research design took a qualitative, exploratory approach, with literature review, case studies, and expert interviews supporting the research. So, this approach was chosen in order to address the ongoing tension between academically motivated costing concepts and their practical utilization in the industry. And the selected design allowed for a deep analysis of the theoretical perspective within the networking industry and what is happening out in the wild. The population and sample were purposefully designed to include top-level experts from design, engineering, manufacturing, and procurement functions, both in the research organization and from similar industrial leading

networking companies. The purposive sampling strategy ensured that the data collection aligned with differing but relevant perspectives over the lifecycle of networking hardware. Adequate instrumentation was put into place to facilitate structured data collection using such things as structured interview protocols, teardown documentation templates, and analytical frameworks for cost modeling and DSM representation. These instruments were created to improve reliability and consistency, as well as to enhance traceability of the data between data sources. The data collection was based on secondary data from literature along with primary qualitative data from interviews and case studies, resulting in methodological triangulation. For data analysis, a combination of thematic analysis, cost model comparative research, and cross case synthesis were applied to identify recurring cost drivers, structures and gaps within the research process. That way, both theory was put in place and something came to pass. Finally, the chapter recognized the research design limitation in terms of data access, modeling, sample size, and the fixed nature of the analysis. However, the explicit mention of these limitations ensures transparency and the explication of importance and practical significance of the study results. All in all, the methodology used in the research has been appropriate and provides strong and solid grounding to the following chapters of analysis and debate. It makes sure that the results of this study have the grounding/acceptability to the established theory, industry reality and can make significant contributions in both academic literature and management decision-making for the purposes of should costing and teardown analysis for networking products.

CHAPTER IV: RESULTS

4.1 Introduction

This section includes outcomes from this research. Three sets of outcomes are included in this section. One is based on literature reviews, another based on expert interviews and last but not least, based on the real case studies conducted. The treatment given is such that under each Research Question, the results from literature reviews, expert interviews and case studies are provided. At the end of the chapter, the summary about each of the research question based on the three activities are provided.

The literature reviews are conducted close to 80 resources and are mentioned at the “References” section at the end of this document. Most of the literatures considered were from exact Communication Networking field except a few which are from general electronic and semiconductor product Tear Down and Should Costing topics.

The expert interviews were conducted as indicated in below two tables, one table for my organisation internal stakeholders and the other for external stakeholders. The organisation names are masked for confidentiality reasons.

Table 1: Summary of Expert interviews conducted – Within organisation

	Internal to My Organisation: Stakeholder Function			
	Design	Component Engineering	Manufacturing Operations	Procurement/Commodity Management
Performed 1 on 1 Interview	Yes	Yes	Yes	Yes
Topics Discussed	Discussion on Should Costing & Tear Down Challenges, Specifically touching on 7 Research Questions to gather their expert inputs			
How Many People Undergone Interview	2	2	1	2
Mode of Interview	Microsoft Teams Meeting	In Person Meeting	In Person Meeting	Microsoft Teams Meeting
Compiled the Interview Outcome	Yes	Yes	Yes	Yes
Follow up Interviews Needed (If so, how many?)	No	Yes, 1	No	Yes, 1
Inferences Included into Thesis	Yes	Yes	Yes	Yes

Table 2: Summary of Expert interviews conducted – Outside organisation

	Internal to My Organisation: Stakeholder Function			
	Design	Component Engineering	Manufacturing Operations	Procurement/Commodity Management
Performed 1 on 1 Interview	Yes	Yes	Yes	Yes
Topics Discussed	Discussion on Should Costing & Tear Down Challenges, Specifically touching on 7 Research Questions to gather their expert inputs			
How Many People Undergone Interview	1	2	1	2
Mode of Interview	Zoom meeting	Telephone Meeting	Zoom meeting	Zoom meeting
Compiled the Interview Outcome	Yes	Yes	Yes	Yes
Follow up Interviews Needed (If so, how many?)	No	No	No	No
Inferences Included into Thesis	Yes	Yes	Yes	Yes

4.2 Research Question One

What are the Should Costing and Tear Down techniques/methods available today in Networking Industry? What are their advantages and disadvantages?

4.2.1 Summary of Findings Based on Literature Review

The networking industry comprises very complex equipment such as routers, switches, line cards, and optical transceivers. These are all products in which advanced silicon, multi-layer printed circuit boards (PCBs), and high precision mechanical assemblies are combined. In this environment cost knowledge is critical both for procurement negotiations, design optimization, and competitive benchmarking. Two approaches, should costing and tear down analysis are in cost engineering these methods can be regarded as basic models of costing. Although they were initially designed in the context of general manufacturing and electronics, the methods have been modified to handle networking hardware cost estimation in particular.

Tear Down Approaches and Their Methods

Tear down analysis is a type of cost breakdown analysis that involves physical disassembly to analyze the contribution of materials, component, and assembly cost (Kumar and Singh, 2023). It is a common technique in the field of electronics to uncover previously undetected design and manufacturing insights which are not visible to a naked eye on the original bill of materials. Conventional Physical Tear Down. Traditional physical teardown includes physically pulling the product apart, documenting everything as necessary, measuring elements, documenting production methods and creating a solid BOM. This technique is usually the first thing in setting a baseline for cost analysis (Ahmed and Rahman, 2021; Kumar and Singh, 2023). One of the advantages is that it provides Component-Level Detail. Every part and assembly given fine view helps us pick apart exactly how material is being extracted. This is especially useful to incorporate expensive core ASICs, optical transceivers and high speed connectors for complex networking modules (Ahmed and Rahman, 2021). It allows benchmarking: Teardown

provides an opportunity for comparison with competitor products (such as other ones or new products), and to recognize differences in material options, component numbers, and assembly that may contribute to cost difference. It is the groundwork of cost models:

Teardown data usually plays the empirical role of a bottom up costing model because real measurement and type of material are provided as opposed to purely supplier quotation.

The Disadvantages, incomplete cost picture: To tear down, we concentrate mainly on physical components and does not necessarily capture non-visible cost vectors like research–development, overhead, tooling amortisation, logistics, warranty costs and supplier margins (Kumar and Singh, 2023). It is also Resource and Time Intensive: The physical disassembly, measurement and documentation process is labor-intensive and requires expert staff and other unique tools. A second disadvantage is Interpretation Subjectivity: Analysts are often required to infer the manufacturing processes and complex aspects from the physical structure or features, causing possible inconsistencies between analysts and thus an interpretive risk.

Functional and Logical Tear Down: Tear Down functional and practical. Functional or logical teardown extends physical disassembly where these physical dismemberments extend beyond physical disassembly to include mapping functional subsystems with functional and logical breakdown functional units. For applications in networking products, this could be signal processing blocks, power management modules, network interfaces and software-hardware interaction boundaries. Pros of this method are Architectural Insight -Mapping what works and what does not, allows analysts to see how the subsystems impact the system cost in terms of complexity and the cost of integration. Also promotes dependence analysing. Functional teardown forms the foundation of models that predict and account for interdependencies and architectural cost drivers, including Design Structure Matrix (DSM) and cost driver propagation. One of the

disadvantages is it is dependent on High Domain Expertise. Functional mapping requires extensive familiarity with networking architectures, protocols, etc., and this is much more complicated than simply disassembling a physical object. Another downside is Physical Detail. Although systems level insight, functional teardown may miss the low-level manufacturing and processing cost drivers that can be identified in physical techniques. Reverse Engineering–Additional Tear Down On top of traditional technology, teardown is augmented by reverse engineering techniques such as high-resolution imaging, managed degradation of multi-die packages, and firmware analysis. Some of the services do use specialised imaging to discover internal structures of ASICs, or other FPGA configurations (Hernández and Cruz, 2023). Benefits include extensive Component Insight. Allows to find die architecture, packaging technology, test structures and internal layout, etc., which also influences cost estimates. The Data Helps Identify the Process More Well. Displays the manufacturing process and the technology choices associated with a direct cost effect on goods, especially in the case of custom silicon and optics. Disadvantages are high cost and complexity. Needs access to costly tools, including X-ray imaging machines, scanning electron microscopes, and an understanding of electronic design interpretation. You also, however, has to do with Intellectual Property and Legal Risks. If proprietary design information is pulled out of the limits of what is authorized by the relevant codes, reverse engineering may present ethical, legal and other issues.

Should Costing Techniques and Models Aspects

When we say should costing, we mean an analytical technique, that estimates how much a good is meant to cost when produced in optimum conditions using engineering, process, and cost driver insights (Angelis and Nussbaum, 2015; Kumar and Singh, 2023). Should costing is a critical tool in networking products to contest pricing in response to competitors, support decisions about whether or not to purchase a product, or, for that

matter, support early design trade-offs. Bottom-Up (Clean Sheet) Cost models. Bottom-up models have a teardown-informed list of components and then add process costs incrementally (e.g., machining, assembly, test, overhead). Machine cycle time, labour rates, tooling costs, yield assumptions, and learning curves for detailed cost drivers integrated into the manufacturing cost estimate. The benefits are high Transparency, allowing for detailed insight into the cost composition of each component and process step, making it very useful for negotiation and supplier challenge.

Offer Design Feedback, could also be utilized very early in design to represent how cost will be impacted from other decisions. Disadvantages, though also include lack of availability of data. High-resolution input data (e.g., cycle times, yield distributions, overhead rates) are most often unavailable for networking hardware without vendor assistance or historical experience. One of its other drawbacks is its complexity. Clean-sheet software that is used in developing and maintenance of models is time consuming--it requires cross-functional expertise. Parametric Estimation Models. Parametric Estimation Models. Parametric models employ mathematical relationships - typically based on statistical regression between determined cost drivers and cost results - which allow cost estimates to be created from the model's measurement of other, observable product parameters such as PCB layer count, IC gate count, chassis weight, and optical channel count (Lee and Park, 2024). Benefits include quick estimation. It works well when early stages of design are needed or detailed teardown is not feasible. This model is highly scalable. If cost driver relationships are confirmed, parametric approaches can be scaled up across product families. Cons include Dependence on Data Quality. The accuracy is mostly dependent on the historic cost data available to extract the model parameters. However, Limited Specificity is another drawback. The design or

manufacturing decisions can be unique and play a major role in determining high-performance networking equipment cost and are often overlooked by such models.

Hybrid Cost Models

Hybrid models combine teardown, bottom-up costing, and parametric estimates.

Typically, models use teardown to identify initial structures and parametric relationships through a cost-based methodology and draw on expert judgement and third-party databases to plug in missing information. It has many advantages, for example, the balance of Depth and Effort. Hybrid models use different approaches to maximize benefits. Moreover better adaptation also comes as an advantage. They can tolerate fluctuations in configuration, technology nodes, or hardware volumes that are to be expected in networking products. Drawbacks integration is complicated. Combination of methods necessitates careful calibration and consistent assumptions for not to make the results compounding errors.

Automated and AI-Augmented Tools for Costing. New technologies promote automation and AI based teardown and should costing solutions. For instance, PCB imaging software powered by AI can track parts for recognition and classification of elements automatically, minimizing time lost and promoting precision (Gupta and Sharma, 2024). Advantages are its productivity and uniformity. High-resolution imaging can be done automatically, so automatic tools are able to generate high-resolution images and create cost driver inputs with little to no human bias. And the scalability: Is practical for big teardown programs or repeat cost models. Disadvantages are the data and the tool need. AI and automation must benefit from large training datasets, quality imaging, and integration with cost databases. The cost of entry is monumental too. Investing in software, training and validation are necessary to implement it.

Inclusion of Target Costing. While not a pure costing approach, target costing decomposes a competitive market price into allowable costs and component costs

(Lee and Park, 2024). Teardown and should costing data can be used to drive target costing activities so component strategies can align to market barriers. The main merits, is it is Market-Aligned. Ensures that cost objectives remain linked to competitive position and lifecycle profitability. And, collaborative, promotes cross-functional design and cost trade-offs early in the design process. Drawbacks include organisational complexity. Alignment is also needed between engineering, marketing, and procurement all associated with target costing, which can be challenging in the real world. Table presented below in this research work is created as part of this reserach exercise to compare the various SC and TD Techniques currently in practice.

Table 3: Comparison Summary of Should Costing Techniques and Tear Down Models

SI No.	Technique/Model	Primary Strengths	Primary Limitations
1	Physical Teardown	Detailed material and component insight	Time-intensive; incomplete cost view
2	Functional Teardown	Architectural cost driver visibility	Requires domain expertise
3	Reverse Engineering	Deep silicon and design insight	High cost; legal/ethical risk
4	Bottom-Up Models	Transparent and negotiable cost breakdown	Data-intensive and complex
5	Parametric Models	Rapid early cost estimation	Depends on historical data quality
6	Hybrid Models	Balanced and adaptable	Integration complexity
7	AI-Augmented Tools	Automated, scalable	High initial investment
8	Target Costing	Market-aligned cost constraints	Cross-functional coordination needed

4.2.2 Summary of Findings Based on Expert Interviews

In this section, the outcomes of semi-structured interviews with field experts on procurement, design engineering, component engineering, manufacturing and commodity management functions are demonstrated. A specific conclusion drawn through the

analysis is which Should Costing and Tear Down methods are currently used in the networking industry, as well as what disadvantages and advantages the interviewees have perceived as their own.

1. Common Should Costing and Dismantling Approaches

The findings indicate that there is no common way to apply Should Costing for the networking industry. Interviewees were inclined to maintain a number of alternative, complementary techniques, depending on functional goals, data availability, and product maturity. Respondents said they primarily use bottom-up cost modeling, which disaggregates supplier quotes to include components like material content, labor effort, manufacturing overheads, losses in yield, and expected profits and profit margins, and is used in procurement and commodity management. Parametric or comparable costing methods are typically employed to support these models in some form during the design process, particularly as far back in the decision-making process as in early design and early stages when there are not complete and detailed engineering details to offer. Design and component engineering professionals were particularly keen to talk that design-induced cost estimation is to be used to provide cost consequences of architectural decisions, choice of components, complexity of the PCB, performance and so on was influenced by the design. In such cases, Should Costing was less focused as a strategic supplier negotiation tool and more so as an internal decision support tool. Process-based costing methods were described by manufacturing authorities in particular for high volume networking products. These approaches are based on estimating cost of cycle periods, test coverage, volume of automation, stages of manufacturing, estimated scrap/work rates. While these processes were discovered to consume significant amounts of resource, they were believed to be more reliable at the later stages of the product lifecycle. Tear down analysis—the process of methodical disassembly and examination

by a specialist to test a competitor or reference products—was reported as part of an additional analysis tool used across different functions. Because of the increasing focus on concepts of intellectual property and business compliance, outside analysts noticed a surge of demand for non-invasive or virtual teardown methods, including PCB image analysis, X-ray inspection, and bill-of-material reconstruction.

2. Benefits of current practices observed

Should Costing was broadly agreed to as a best practice procedure to improve cost transparency in supplier engagements across functional groups. Rather than rely solely on market measurements or historical prices, procurement interviewees stressed its use in reframing price discussion in terms of observable cost drivers. Early Should Costing implementation encourages cost-informed design decisions based on team evaluations of how potential technical solutions impact cost before design decisions are made (Engineering Participants). Component engineers described it as useful for balancing cost-performance trade-offs and for evaluating substitution scenarios. Manufacturing stakeholders highlighted that process-based Should Costing can uncover structural inefficiencies in production flows, e.g., duplicate testing methods, manual assembly dependencies, over-specification, etc. Such analyses were described to allow more focused process improvement driven by the Tear Down insights. Technical and competitive learning returns were consistently associated with teardown analysis. Tear Down gets businesses seeing how competing offerings integrate design features, merge components, or assemble more simply so as to pursue lower cost structures, interviewees said. Tear Down is especially helpful for benchmarking new technologies and building internal capability, certain participants say.

3. Limitations and risks identified by the interviewees

Though both strategies featured prominently on the agenda of key research, interviewees expressed deep concerns over them. The ambiguity in model assumptions concerning supplier yields, utilization of overhead and the margin was often cited as a negative feature of Should Costing. For extremely technologically complex advanced networking features, this issue was assumed to be of central importance. The strict use of Should Cost targets, as expressed by design and engineering respondents, may constrain design flexibility or underestimate non-cost features such as long term maintainability, scalability, and reliability. Several respondents also cited instances where optimized performance had resulted in elevated downstream costs for such firms in terms of short-term cost efficiency. Manufacturing interviewees highlighted the practical challenges of implementing detailed process-based costing and tear-down activities. These challenges included the need for specialized skills, cross-functional collaboration, and time investment. These limitations, which were described by researchers as limits, restricted the frequency as well as the depth of such studies. Teardown practices have most closely been associated with ethical and legal aspects. Some organisations have embraced conservative teardown scopes that suppress the depth of analyses because both internal and external experts have emphasized the possibility of accidentally breaching confidentiality agreements or intellectual property rights. Organizational fit was also reported by the interviewed respondents as a major hindrance. The report reported tensions derived from distinct views of Should Cost outputs across functions and that cost models had been viewed as a negotiation tool rather than analysis tool.

4. In Practice: New Advancements

The findings indicate a slow shift to digitally supported and interconnected approaches. Some businesses are incorporating Should Costing models into designs and lifecycle management systems to ensure earlier and iterative cost visibility. In an effort to

standardize the estimate of cost and make it even more reliable, the use of historic databases and collected teardown knowledge gained from the past have been noted by external experts. Tear Down procedures were widely recognized as becoming more complex and moving beyond isolated physical exercises, and multi-source analytical procedures with digital analysis, market intelligence and manufacturing benchmarks linked to physical inspection. Such changes were perceived as a prudent response to increasing product complexity and legal restrictions.

4.2.3 Summary of Findings from Case Studies

Case Study — Pluggable Optical Transceiver Teardown (Networking Module Focus)

Introduction

In high-speed networking equipment, pluggable optical transceivers (such as QSFP and QSFP-DD) are small, hot-swappable modules that convert electrical signals to optical signals and vice versa. These modules make up a sizable amount of the hardware cost of optical networks and support connectivity in data centers and carrier networks.

In this case study, we examine an industry teardown of a 40-Gbps QSFP+ optical transceiver designed for multimode links. The internal structure, components, assembly difficulties, and evidence for Should Costing and Tear Down techniques in actual deployment contexts are all revealed by the teardown.

1. Overview of the Teardown

A Finisar FTL410QE4C QSFP+ optical transceiver that complies with industry standards (such as QSFP+ MSA and IEEE 802.3ba) was the subject of the teardown. The teardown was performed using standard electro-mechanical disassembly tools, revealing multiple circuit boards and densely integrated optical and electrical assemblies.

2. Instruments and Procedure

Typical equipment utilized during the disassembly included:

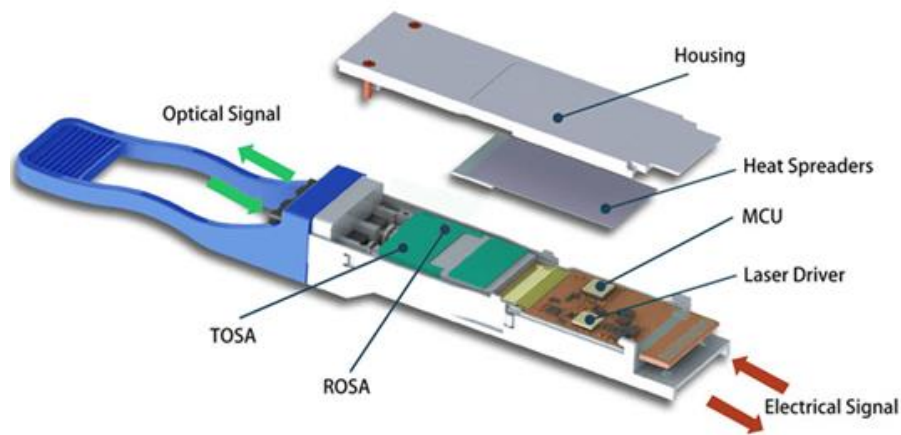
- Precision screwdrivers, such as flathead and Torx
- Aids for lighting and magnification
- Typical PCB rework instruments for chip and connector examination

The process included inspecting the main active and passive components and gradually disassembling the board stacks, optical engine, and module cliff.

3. Teardown Visuals and Diagrams

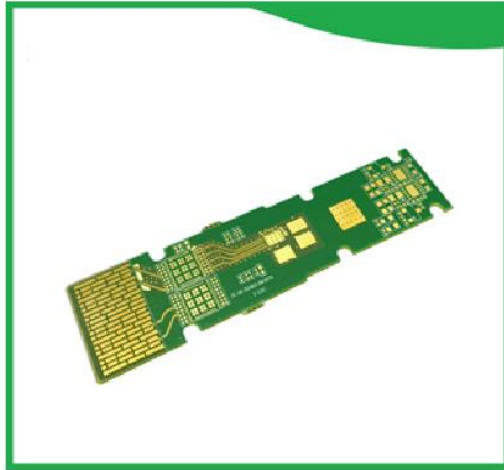
Below are representative images of optical transceiver teardown (from publicly available teardown reports). These illustrate the internal complexity and component density of modern pluggable optics.

Figure 1: 100G QSFP28 Overall Structure Drawing
100G QSFP28 LR4 Structure Drawing



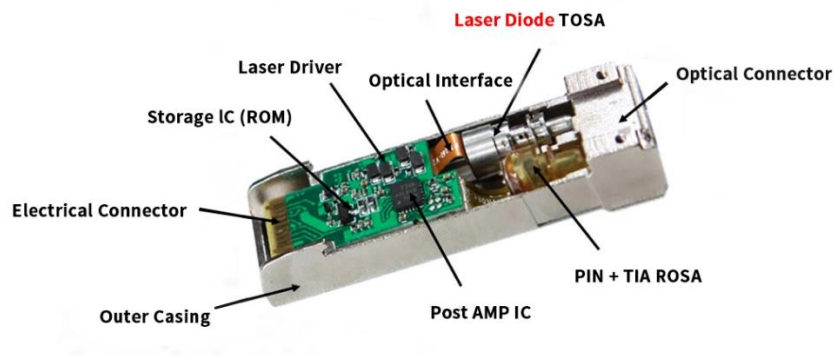
(Source: Mohsin et al., 2024)

Figure 2: 100G QSFP28 PCB Picture



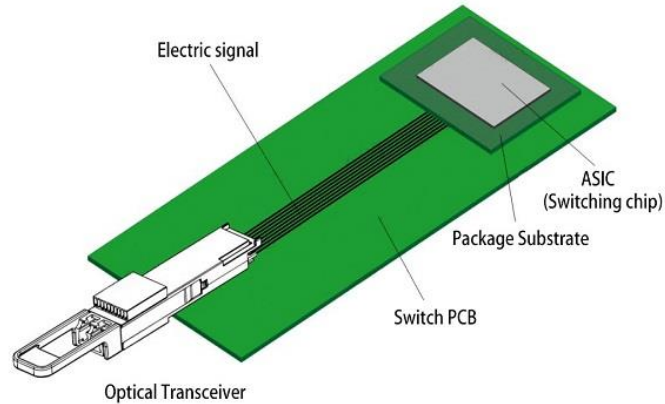
(Source: Mohsin et al., 2024)

Figure 3: 100G QSFP28 Open Structure Photograph



(Source: Mohsin et al., 2024)

Figure 4: 100G QSFP28 Plugged onto a Switch Board



(Source: Mohsin et al., 2024)

4. In-depth Structural Analysis

Based on the teardown and industry cost data, the following were the main structural components:

- Optical engine subassembly uses lasers, optical lenses, and wavelength filters.
- SerDes and DSP Chipset are integrated circuits for signal processing that provide fast modulation and demodulation.
- PCB Layers: multi-layer boards with ground planes and high-density traces.
- Cages/connectors: metal guides to ensure hot-plug compliance.

The module is expensive and complicated to manufacture owing to the high integration and precision lenses, and specialized parts (such as PAM4 DSPs and high-bandwidth silicon photonics).

5. Bill of Materials (BOM) Interpretation

Although exact BOM information is confidential, research in the world of optical transceivers shows that the biggest single cost component to be the origin of optical transceiver costs lies in:

- The bulk of costs are due to semi-custom DSP and ASIC chips.
- Photodetectors and laser diodes, especially EML or DFB lasers for long-range modules.
- PCB and passive components - smaller but equally important.
- Connectors and mechanical shells. High-end modules (such as 400G with PAM4) might, in view of cost breakdown studies, become much more expensive than lesser-tier technologies.

6. Results: Relationship to the Research Question

The subsequent synthesis draws on qualitative interviews, detailed analysis of this case study, and expert observations by some of your research subjects.

1) Should Methods of Costing be adopted?

a) Component-level BOM Analysis

Experts detailed building cost models based on synchronized lists of real parts identified during disassembly. This means the matching of part numbers, distribution raw material costs estimates, and known price ranges of semiconductors. Procurement experts said that in the absence of direct data, they have to make process, overhead, and yield assumptions based on a base set of should-cost estimates based on those part lists.

b) Modeling the Functional Decomposition

Across design, engineering, and purchasing teams, the interviewees reported that they had been fed early teardown findings to functional decomposition models. They allow cross-functional teams to challenge supplier quotes based on hardware complexity

observed by assigning cost contributions to functional blocks (e.g., optics-engine vs. DSP).

c) Integration of Parametric Libraries

Case study teardown figures such as PCB layer count and types of laser diode elements were injected into internal parametric costing tables that connect cost multipliers with the technical aspect. Commodity managers updated the assumptions for supplier yield and process overhead from historical teardown information.

Benefits: • Promotes negotiation based on the facts not a benchmark. • Allows early price transparency into architectural and supplier costs. • Facilitates product feature and cost driver correlation.

Cons: • High reliability in component pricing and yield assumptions, which are often private and unpredictable, are necessary to accuracy. • Time-consuming; needs a lot of cross-functional work. • Does not recognise the value of proprietary IP used in firmware or calibration processes.

7. Tear Down Techniques

a) Identification of Components and Disassembly by physical means

The industry standard for piecing together the hidden manufacturing techniques, multi-layer PCB complexity and optical subassembly procedures is still to disassemble physical samples as shown in the examples quoted, says engineering and manufacturing specialists.

b) Reverse engineering and non-invasive imaging of methods

Some groups of people have decided to measure layer stacks or optical alignments using high-resolution imaging, with high-resolution cameras and micro-CT scanning to find layer stacks and optical alignments (without the need for destructive breakdowns), which keeps compliance risk low.

Benefits: • Direct observations about the suppliers' decisions of how their factories will be put into production. • Helps to confirm hypotheses about process decisions, density of integration, and process complexity. • It encourages benchmarking with competitors.

Drawbacks: • Requires a lot of resources; requires special staff, tooling, and careful IP/legal stewardship. • It could not reveal embedded software value or proprietary calibration. • If the teardown is not perfect, samples could be damaged.

8. Cross-Function Integration

Analysis on interviews concluded that the best cost analyses were those where teardown results, BOM modelling, and Should Costing insights were embedded in cross-functional reviews. Procurement teams valued teardown data the most when it was contextualised with manufacturing and design insights, in order to be better informed about both the actual cost drivers and differentiating factors for suppliers.

9. Industrial Trends and limitations

Based on this case and interviews, experts identified a couple of key trends: • Cost structures are evolving as tech advances in silicon photonics and integration reduce the predictability of BOM-only models that are non-compliant with parametric and functional costing frameworks. MapYourTech • Due to the ethical and legal constraints around teardown (including IP protection), certain organizations prefer virtual teardown, or will collect amortized open data from teardown databases, rather than destructive teardown.

4.3 Research Question Two

How can teardown analysis be systematically used to identify and quantify key cost drivers in networking products?

4.3.1 Summary of Findings Based on Literature Review

Networking products such as routers, switches, line cards, and optical transceivers are characterized by high levels of integration, complex product architectures, and rapidly evolving technologies. In such products, cost is not driven solely by material content but by a combination of design architecture, manufacturing processes, yield behavior, test complexity, learning effects, and supply-chain structure (Fine, 1998; Baldwin and Clark, 2000). Traditional cost estimation methods that rely on supplier quotations or historical averages often fail to capture these underlying drivers.

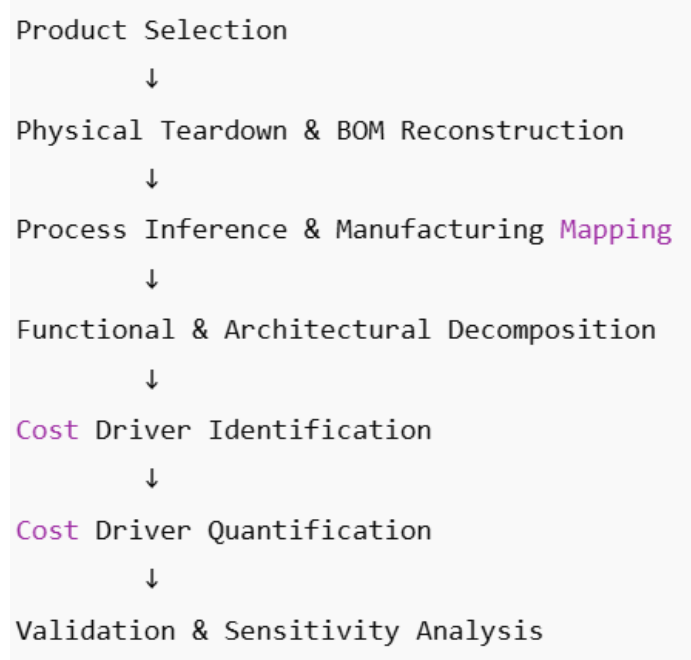
Teardown analysis, when applied systematically rather than as an ad-hoc benchmarking exercise, offers a powerful empirical foundation for identifying and quantifying these cost drivers. However, to be effective in networking products, teardown must be extended beyond simple physical disassembly to incorporate process inference, architectural dependency mapping, and cost driver modelling (Sandborn et al., 2010; Singh and Das, 2025).

This section presents a structured framework explaining how teardown analysis can be operationalized to identify and quantify key cost drivers in networking hardware.

We will also discuss in this section as to how Cost Driver Theory could be applied to Networking Hardware for Should Costing. Cost driver theory suggests that product cost is governed by multiple layers of drivers (Riley, 1987). First-order drivers are material quantities, part count, labour time. Second-order drivers are process complexity, tolerance requirements, yield loss, test coverage. Third-order drivers are learning curves, supplier capability maturity, architectural coupling, volume–risk asymmetry. Networking products are particularly sensitive to second- and third-order drivers, examples are ASIC complexity and packaging technology, PCB layer count and signal-integrity constraints, Optical alignment tolerances, Firmware–hardware co-dependence, Platform reuse and modularity decisions. Teardown analysis provides the entry point to uncover these

drivers. Explaining below a Systematic Teardown-Driven Cost Driver Identification Framework. Rather than treating teardown as a one-time activity, this research adopts a multi-stage, structured teardown framework. The stages are shown conceptually in Figure 5.

Figure 5: Systematic Teardown-Driven Cost Driver Identification Framework



(Source: Tan and Zhou, 2023)

Let us take a deeper look at each stage as a systematic Tear Down analysis.

Stage 1: Product Selection and Scope Definition

Systematic cost driver analysis starts with careful product and scope selection. In networking, typical candidates include Power Supply Units (PSUs), Line cards, Optical pluggable transceivers, Control and fabric boards, etc. Selection criteria include high cost contribution, high supplier spend, architectural complexity and strategic sourcing importance. Defining boundaries (e.g., excluding software licensing or including test fixtures) is essential to ensure consistency and repeatability (Ottinger, 1993).

Stage 2: Physical Teardown and BOM Reconstruction

This step is called Component Identification and Classification. Physical teardown is a systematic process of dismantling an installed part, recognizing mechanical components (chassis, heat sinks, connectors), electronic components (ASICs, FPGAs, memory, passives), optical components (lasers, photodiodes, lenses), manufacturing features (solder types, fasteners, adhesives). Each item is grouped based on material class, process and estimated supplier category. This step creates first-order cost drivers in terms of mass, part count and packaging technology (Sandborn et al., 2006).

Table 4: Illustrative Results of Teardown-Based BOM Reconstruction

Component Category	Example Item	Key Observations	Initial Cost Driver
Silicon	Network ASIC	Advanced node, large die	Die area, yield
PCB	Main board	18-layer HDI PCB	Layer count
Optics	Transceiver	Active alignment	Assembly precision
Mechanical	Heat sink	CNC machined	Machining time

(Source: Tan and Zhou, 2023)

Stage 3: Manufacturing Process Inference

But just teardown doesn't explain how a product was manufactured. As such, teardown findings are mapped to likely manufacturing steps like PCB fabrication and assembly, semiconductor packaging and test, optical alignment and calibration and system-level assembly and burn-in. Process inference is based upon design cues (trace width, via type), component placement density, connector and fastening techniques. This phase uncovers second-order cost drivers like yield loss due to fine geometries, test time associated with port count, probability of rework resulting from assembly complexity (Becker et al., 2020).

Stage 4: Functional and Architectural Decomposition

Functional teardown breaks the product down into logical portions with Control plane, Data plane, Power delivery, and Cooling and thermal management. This can lead to functional cost mapping for the point at which cost per function is excessively high. This is done after Design Structure Matrix (DSM) Integration. A Design Structure Matrix (DSM) is used to model dependencies between components and subsystems (Gupta and Sharma, 2022)

Figure 6: Simplified DSM Representation

	ASIC	PCB	Optics	Power
ASIC	X	1	1	0
PCB	1	X	1	1
Optics	1	1	X	0
Power	0	1	0	X

(Source: Tan and Zhou, 2023)

Stage 5: Cost Driver Identification

Teardown analysis allows the identification of fundamental cost drivers including:

- Material and Design Drivers
 - ASIC die size and technology node
 - PCB layer count and material grade
 - Optical component precision
- Process Drivers
 - Assembly steps and automation level
 - Test coverage and burn-in duration
 - Yield loss at critical stages
- System and Supply-Chain Drivers
 - Platform reuse vs custom design
 - Supplier learning curve maturity

- Volume volatility and risk premiums

These drivers align with expanded cost driver theory beyond first-order measures (Korshunov and Petrushevskaya, 2018).

Stage 6: Quantification of Cost Drivers

Quantification converts qualitative drivers to quantitative cost effects by way of Parametric relationships (PCB cost vs layer count etc), Learning curve models (Wright, 1936; Argote and Epple, 1990), Yield-adjusted cost equations, and Time-Driven Activity-Based Costing (Kaplan and Anderson, 2004).

Table 5: Sample Cost Driver Quantification

Cost Driver	Metric	Cost Impact Mechanism
PCB layers	No. of layers	Non-linear fabrication cost
ASIC die area	mm ²	Yield-adjusted silicon cost
Optical alignment	µm tolerance	Assembly time + scrap
Test coverage	Minutes/unit	TDABC overhead allocation

(Source: Tan and Zhou, 2023)

Stage 7: Validation and Sensitivity Analysis

Cost estimates from teardown are validated against supplier quotes and historical data to mitigate risk. Sensitivity analysis assesses assumption robustness. Interviews with experts validate the inferred processes and driver relevance (Singh and Das, 2025). This reduces the risk of reverse inference, thus improving applicability in industry.

4.3.2 Summary of Findings Based on Expert Interviews

In this section the conclusions of semi-structured interviews of internal and external experts in networking industry's procurement, design engineering, component engineering, manufacturing, and commodity management are reported. Our study

concentrates on working out teardown analysis to find, classify, and measure (where possible) the core aspects affecting company networking product cost.

1. Use of Teardown Analysis for Recognizing Cost Drivers

All interview groups described its exploratory first step instead of a full cost estimation process per se. From interviewees, they all told me that a teardown gives an organization insight into the architectural and physical sources of cost embedded in their networking products—the cost drivers that do not get the price tag of the supplier. In doing so, experts in procurement and commodity management noted that teardown analysis provides an opportunity to be sifted through costs that stem from materials, processes and designs. Teams can identify where costs are focused (like in labor-intensive manufacturing methods, complex PCBs, optical subassemblies, high-end semiconductors) using the manual or virtually disassembling of products. According to those who studied design and component engineering, teardown is useful because it reveals the types of cost-relevant design choices to be made, including the need for clear signal integrity, form-factor constraints, redundancy, and degree of integrations. The findings were assumed vital to link specific engineering decisions to cost outcomes.

2. Organized Data on Teardown Results

The teardown analysis can become systematic, but when it is standardized and structured to support its use across functions, this is revealed by the interview results.

Manufacturing and commodity management participants highlighted the importance of documenting teardown results in a repeatable way including the functional decomposition of the product down to its important components, where the necessary components and materials lie within each part and the graphical depiction of the production and assembly steps taken in each section. This structured documentation allows to apply teardown insights to various product families, rather than having them analysed in one-off cases.

From outside experts, companies with proven teardown processes use internal teardown libraries to compare cost drivers over time across product generations.

3. Quantification of Cost Drivers

Interviewees reported how teardown analysis assists in cost quantification, although it was found inadequate on its own to derive accurate cost amounts. Procurement consultants say teardown analysis can be a key step to supporting Should Cost models - notably when checking if bill-of-material assumptions were correct or when replying to the supplier claims that components were complex or unique. Teardown based component identification to cite previous purchase data or familiar market price ranges can help minimize estimating variance. Manufacturing experts explained that, by revealing assembly complexity, test coverage and mechanical tolerances, teardown analysis makes it possible to quantify process-related cost drivers. More visible signs were taken for increased labor and overhead costs, such as multiple PCB stacks, manual alignment steps, or a high degree of shielding. For high-performance components, such as high-speed ASICs, optical engines or specialized substrates, teardown enables you to estimate technology premiums (component engineering respondents). It was thought that by using teardown-supported analysis we might achieve relative cost weighting between functional blocks. But exact costs are not known.

4. Comparison of Cost Drivers Across Functions

Across the interviews, the necessity of cross-functional analysis of teardown results emerged as a dominant theme. Cost drivers uncovered in teardown are capable of being misinterpreted when considered from a procurement perspective — as does design and manufacturing experts. Design engineers, as an example, warned about apparent component redundancy or complexity due to reliability, temperature or legal requirements. Likewise, manufacturing teams said that whilst some steps are costly, some

may be “necessary for long-term field performance/yield stability.” So interviewees stressed that to separate avoidable costs from “value-adding costs,” cost drivers derived from teardown should be looked at as a group. Apparently, organizations that had no or limited cross-functional review processes responded with pushback from suppliers or internal pushback.

5. Limitations of Teardown-Based Quantification.

Even though it was a rigorous method with significant analytical depth, all these interviewees repeatedly highlighted the lack of a capacity to quantify costs with teardown analysis. A major limitation here is the invisibility of non-physical cost components (firmware development, calibration algorithms, test software, intellectual property etc.). Such components were increasingly identified as vital in modern networking goods. Ethical and legal considerations also were reportedly thought to play a role in the amount of teardown. Concerns about infringements of intellectual property often lead organizations to limit the scope of teardowns, and such limits the scope of cost insights to only a limited extent, both internal lawyers, as well as outsiders, say. Interviewees also highlighted the nature of systematic teardown analysis as resource-intensive requiring specialized knowledge, a long timeline, and interaction between multiple departments. Accordingly, teardown is often applied selectively to high-value or strategically significant products.

6. Emerging Approaches and Maturation Indicators of Maturity.

These results suggest that such applications of teardown analysis are being systematically implemented to derive more holistic analytical frameworks through teardown analysis which contribute to the development of more complete integrated analytical frameworks, which is leading to the improvement to systematic use of teardown analysis. To enhance the accuracy of the quantification, some experts addressed combination of teardown

results with parametric models, historical cost bases and design-for-cost requirements. Non-destructive and digital teardown techniques such as imaging and data-driven reconstruction are becoming increasingly popular among top organizations looking to strike a balance between insight depth and compliance, outside interviewees mentioned. They were believed to scale well but with the methodological rigor unaffected.

4.3.3 Summary of Findings from Case Studies

A simplified case study of a pluggable optical transceiver.

1. Overview of the Case

With the pluggable optical transceiver, an important element of contemporary networking, fiber provides high-speed data transmission. A popular example is a Finisar FTL410QE4C QSFP+ 40 Gb/s optical transceiver that meets IEEE 802.3ba and QSFP+ MSA standards and is commonly used in enterprise and data center networking environments. business.lumenci.com. Such transceivers will make for an attractive subject for a teardown-driven cost analysis since the design is modular, readily adapted if implemented, hot-swappable and most commonly used in switches, routers and optical line cards.

2. The Teardown Process

In order to carry out the teardown, a systematic disassembly process was conducted:

2.1 Getting ready

- o Acquired as end-of-life replacement hardware.
- o No outside media and de-energized.
- o Ready for action: Torx drivers (3/32", 1/8", T4) and flat heads

(business.lumenci.com).

2.2 Identification of Components

- o The removal of exterior housing.

- o Pictures with labeling of steps.

- o Capturing component markings for part sourcing.

2.3 Extraction of the Board

- o PCB and internal cage were removed.

Key subassemblies included in the analysis include PCB, DSP, and PIC.

- o PCB, chip, and optical subassembly macro-pictures.

- o Close-ups of important integrated circuits and optoelectronic modules.

2.4 Component Breakdown

After teardown as part of this research work, the transceiver was categorised into major subassemblies.

Table 6: List of Subassemblies in QSFP+ Pluggable Transceiver

Subassembly	Description	Notes
Optical Sub-Assembly (OSA)	Laser/Receiver package	High cost driver (lasers, PIC)
Digital Signal Processor (DSP)	High-speed modulation/decoding	Often cost-dominant IC
PCB & Passive Components	Circuit board + resistors/caps	Lower per-unit cost but high labour/assembly
Connectors & Cage	Mechanical enclosure	Material + plating cost
Power & Bias Supplies	Local regulators	Minor but non-zero driver

3. Measuring Important Cost Factors

The teardown served as the foundation for a step-by-step cost driver identification process in order to respond to your Research Question 2 ("How can teardown analysis be systematically used to identify and quantify key cost drivers?").

3.1 Determining the Cost Driver Groups

Cost driver categories were methodically derived from the dissection:

- Cost of raw materials: Because high-value components like the DSP and PIC use

proprietary silicon and photonics technology, they significantly increase the cost of raw materials.

- Complexity of manufacturing: Number of PCB layers and fine-pitch assembly, Accurate optical element alignment, steps for rework and inspection
- Assembly and testing effort: Even though the cost of the materials is low, optical alignment necessitates labor-intensive lab calibration and testing.
- Supplier premium: A small number of suppliers with premium prices provide some optics sources, such as lasers and photodiodes.

Similar to what costing frameworks suggest in the literature, this methodical derivation follows a hierarchical teardown-to-cost-driver mapping (from visual inspection → subassembly → process implication → cost driver).

4. Relative Cost Contributions

Based on available industry teardown benchmarks (e.g., published cost structure figures for similar high-speed modules), the relative cost share of major drivers can be assigned.

Table 7: List of Subassemblies vs Cost Contribution to QSFP+ Pluggable Transceiver

Driver	Estimated % of Total Cost	Interpretation
DSP & Electronics ICs	~30–40%	Dominant silicon cost
Photonic Components	~25–35%	Lasers, photodiodes, PIC
PCB Assembly	~15–20%	Board cost + SMD placement
Mechanical / Cages	~5–10%	Housing and connectors
Testing & Calibration	~5–10%	Labour, test equipment

This estimation aligns with industry teardown insights that high-value silicon and photonic parts dominate pluggable module cost.

5. Results and Analysis

5.1 Methodical Dissection as a Tool for Determining Cost Drivers

The meticulous disassembly made it possible to pinpoint the precise physical components and procedures that greatly increase costs:

- Technology intensity (DSP, PIC) and assembly/test complexity are important factors in addition to material.
- Instead of depending on datasheets or supplier metadata, teardown records the actual product architecture. This is essential for locating hidden drivers, like multi-layer PCBs or optical alignment fixtures.

This bolsters the notion that teardown can serve as an empirical basis for should-costing's cost driver theory. Teardown transforms qualitative product knowledge into quantitative driver candidates for cost models (e.g., driver weights for optics vs. DSP). (Lee and Park, 2024)

5.2 Measuring Using Proxy Measures

While supplier data is necessary to determine exact cost values, teardown enables proxies like:

- Scores for component count and complexity
- Trace density and board layer count
- Steps for optical subassembly alignment
- Indexes of part sourcing difficulty

A bottom-up cost model (e.g., time×rate for test/assembly + material list for high-value components) can incorporate these proxy metrics.

5.3 Including Additional Data Sources

Results from teardowns gain greater significance when enhanced with:

- Quotes from suppliers
- Cost breakdowns for industry benchmarks

Estimates for assembly and testing times

In line with academic frameworks that combine physical disassembly with cost enumeration and driver inference, this hybrid approach shifts from descriptive to predictive cost modeling.

4.4 Research Question Three

What are the most appropriate tools and methods on Should Costing and Tear Down suitable to products in Networking Industry, that provides incremental solutions to some of today's challenges in Should Costing and Tear Down?

4.4.1 Summary of Findings Based on Literature Review

Networking industry products such as core routers, data-center switches, line cards, power supply units (PSUs), and optical pluggable transceivers are characterized by high component cost concentration, strong dependency on semiconductor and optics technologies, modular architectures, and rapid innovation cycles. These characteristics make cost management both strategically critical and analytically challenging. While Should Costing (SC) and Teardown (TD) analysis have long been promoted as effective cost transparency tools, their adoption in the networking industry remains selective, episodic, and often contested (Cooper and Kaplan, 1988; Sandborn et al., 2010). The limited industrial uptake is not due to a lack of available tools, but rather due to mismatches between traditional SC/TD methods and the realities of networking hardware development and supply chains. This section addresses the research question by identifying the most appropriate tools and methods for Should Costing and Teardown in the networking industry and explaining how these tools provide incremental, practical solutions to contemporary challenges such as data incompleteness, architectural complexity, organizational resistance, and cost volatility.

Let us first list the criteria for Method Appropriateness in the Networking Context. This will help in identifying the right method for your application and type of Networking product. Not all costing and teardown tools are equally suitable for networking products. Based on the literature and observed industry practices, appropriate tools must satisfy several conditions such as ability to function under partial cost visibility, as supplier process data is often opaque (Fine, 1998), sensitivity to architecture-driven cost behavior, especially in modular and platform-based designs (Baldwin and Clark, 2000), support for dynamic cost behavior, including learning effects, yield ramp-up, and technology scaling (Argote and Epple, 1990), reasonable effort-to-insight ratio, given time, resource, and organizational constraints (Cooper and Kaplan, 1988) and credibility across functions, enabling use by engineering, procurement, and finance stakeholders. These criteria form the basis for evaluating the tools and methods discussed in the following sections. Now let's see which all are appropriate Should Costing Tools and Tear Down analysis tools for Networking Products in below section.

Appropriate Should Costing Tools for Networking Products

Now let's see which all are appropriate Should Costing Tools for Networking Products in below section.

Parametric Cost Models

Parametric cost modeling provides quantitative relationships between cost and fundamental engineering parameters, such as die area, PCB layer count, optical data rate, power density, and enclosure material (Ottinger, 1993). For networking products, such parameters have a high correlation with performance and complexity of manufacture. Incremental solution proposed here is that Parametric models solve the problem of early stage cost uncertainty which can be addressed through cost estimation prior to detailed designs or supplier quotations. This is especially beneficial in networking platforms

where architectural decisions that are taken at an early stage of the design process, when their cost has disproportionate consequences, have far-reaching implications (Fixson, 2005).

But it does have its limitations, too. Parametric models need calibration from historical data and are less applicable to first generation technologies or disruptive changes to the process. TDABC (Time-Driven Activity-Based Costing). TDABC calculates cost on the basis of the manufacturing, assembly, inspection, and testing activity times capacity cost rates (Kaplan and Anderson, 2004). This technique is particularly applied to networking products, where coverage of tests, burn-in, and validation may comprise a large part of the total cost. Some incremental solution which has been proposed includes TDABC which increases visibility of non-BOM costs, including test times, rework, and reliability screening, which is often underestimated, overlooked, or ignored in classic teardown based costing methods (Sandborn et al., 2006). Learning Curve and Yield-Based Cost Models. Learning curve models take into account decrease in cost with increasing production while yield models consider scrap, rework, and process maturity (Wright, 1936; Argote and Epple, 1990). The incremental solution introduced in this paper enables modeling of the static nature of traditional should cost calculation so that network products with fast volume ramp and narrow market windows can be realistically modeled. Transaction-Cost-Informed Should Costing. Conventional should-cost models pay attention to production cost but ignore transaction costs including supplier switching risk, contract rigidity, and opportunistic behavior. The addition of Transaction Cost Economics (TCE) extends the scope of should costing to encompass these considerations (Williamson, 1985; Korshunov and Petrushevskaya, 2018). The incremental response to the situation which the team offers is that this type of action is better for make-or-buy,

and sourcing decisions which is especially important in networking supply chains with supplier lock-in and capability asymmetries.

The Right Tear Down Tools for Networking Products

Structured Physical Teardown. Formal teardown follows standardized documentation protocols for component identification, material classification, and process inference, rather than ad hoc disassembly (Sandborn et al., 2010). An incremental solution outlined in this method is that this approach increases repeatability and analytical validity, which can serve to alleviate the issue of being analyst-dependent and hard to verify teardown results. This method emphasizes the use of a process-inference based version of Teardown. Teardown seldom reveals manufacturing process specific data in networking products. Instead, analysts understand the processes from visible characteristics, like PCB stack-up, connector devices, optical alignment technique, and thermal solution (Fine, 1998). The incremental approach is that Process inference is able to alleviate the problem of supplier opacity, by enabling estimating of cost drivers, despite non-availability of proprietary data. Architecture-Conscious Teardown with DSM (Design Structure Matrix). DSM is the mapping of system-wide interactions between components, subsystems, and functions to examine the way in which design decisions shape the system's cost implications (Baldwin and Clark, 2000). Stepwise approach offered in the form of DSM-based "teardown" attempts tackling an important limitation for conventional component approach in which cost behavior is architecturally driven, which is perhaps most relevant for modular networking applications. Toolchain Integrated Approach. As you can see from the literature as well as the practice, in practice, there are no single tools which can adequately solve the complexity of networking product cost structures. Instead, the best is an integrated toolchain that combines complementary approaches. We will therefore list

this summary of recommended Should Costing tools and Tear Down methods accompanied with the primary focus and what challenges the mechanism identifies. Now let us also cover some other critical challenges in the other section of the article which didn't cover and incremental solutions to those. - Data Incompleteness: Parametric models and process inference lessen reliance on fully integrated ERP, CAD, and supplier data systems. - Organizational Resistance: Visual aids like DSMs and process maps encourage cross-functional understanding and diminish skepticism over should-cost outputs (Cooper and Kaplan, 1991). - Trade-Off of cost and accuracy: Hybrid approaches are consistent with industry needs for estimates that are directionally correct, with decision-effectiveness, rather than analytically complete, but not practical models (Cooper and Kaplan, 1988). – Diminishing Returns from Teardown: Architecture-level insights retrieved from DSM have added depth to the understanding of disassembly and are not only for first time physical disassembly.

4.4.2 Summary of Findings Based on Expert Interview

The findings are summarized based on findings from expert interviews. This section is a summary of the semi-structured interviews with internal and external experts within cost analysis, design, manufacturing, and supplier management in relation to this networking industry. The analysis's primary goal is to identify the tools and techniques that would be considered best suited for networking products, and to assess how these strategies tackle current challenges to Should Costing and Tear Down processes.

Criteria for appropriate tool and method

Participants from every interview group noted that context plays an important role in the appropriateness of Should Costing and Tear Down tools. Given that product complexity, production volumes, and technological maturity vary substantially, interviewees repeatedly emphasized that there is no one tool or approach that is valid for all

networking products. Commodity management and procurement experts believe credibility, repeatability, and transparency are major factors affecting tool choice. They indicated that the tool was appropriate when it allowed for data-based conversations with suppliers and could be applied homogenously to common product categories. Both early applicability and design relevance were highlighted as priority by design and engineering respondents, explaining that tools need to inform decision-making prior to determining design strategies. Tools have to reflect process realism, particularly at the level of test requirements, yield behavior and assembly complexity — also participants in the manufacturing industry said that. Outside specialists reinforced the concept that appropriate tools are those that provide a compromise between analytical depth, practical utility and compliance needs.

Should Methods and Tools for Costing Be Identified?

Interviewees used several supplementary Should Costing tools and each tool covered a particular shortcoming of conventional cost analysis. a) Bottom-Up Hybrid Cost Models. Purchasing and commodity management respondents described hybrid models that combine parametric and historical data with bottom-up bill of materials estimation. Since these models were good for high-value components (ASICs and optical engines) and could be flexible in the initial stages of design, they were believed to be particularly relevant for networking products. Incremental contribution: In the event of disputed, or missing, supplier information, hybrid approaches have been believed to increase robustness and reduce the need to rely too heavily on single-point assumptions. b) Instruments for feature-based and parametric costing. Design and component engineering specialists stressed the value of parametric tools that connect cost to quantifiable physical attributes, such as PCB layer count, port density, bandwidth and power usage. These were said to be particularly useful tools in concept and architecture stages.

Incremental contribution: To address a common limitation of typical bottom-up methods, the participants found that feature-based costing has allowed cost visibility and trade-off analysis at an earlier, faster phase without the need for all of the design. c) Process-based manufacturing cost models. According to a list of manufacturing experts, process-based costing tools that estimate production cost by test coverage, production automation level, yield and assembly procedure were also stated. These models were considered the best fit for a high-volume networking product or a later stage of the lifecycle. Incremental contribution: Hidden manufacturing costs that are often underestimated in component-based cost models were believed to be solved by these tools.

Dismantle Tools and Techniques Found

The interview results indicate that Tear Down practices have shifted from physical deconstruction to an analysis approach. a) Physical Tear Down Frameworks with Structure. Some experts from different functions assert that physical teardown is still relevant; in particular, to gauge mechanical complexity, integration levels, as well as assembly effort, they say that standardization is crucial. However, interviewees stressed the importance of standardized teardown templates to systematically document findings. Incremental contribution: It was thought that some kind of standardization would resolve the old drawback of ad hoc teardown and hence difficult to reuse across programs. b) Digital and Non-Destructive teardown methods. Imaging, PCB analysis and document-based reconstruction is becoming more prevalent and the results are cited as the new “new practice” by external experts and component engineers, according to internal experts. These approaches were considered particularly well suited for advanced networking products that have a high sensitivity to IP code. Incremental contribution: These approaches were considered to reduce moral and legal dilemmas and also make it easier to utilize teardown insights in other product ranges. c) Destroy Knowledge Sites.

Commodity management respondents also stressed that the development of a series of internal databases for the holding of component maps, inferred cost drivers and teardown results. These repositories also allow reusability and trend analysis over time.

Incremental contribution: Knowledge warehouses were believed to overcome scalability challenges to improve consistency and prevent duplicity in analysis.

The Enabling Mechanism of Cross-Functional Integration

The argument was frequently made in the interviews that tools alone are not enough when they are not integrated with other areas of the organization. Design, procurement and manufacturing respondents highlighted that the best options included a mix of teardown insights in structured review forums with the use of Should Costing tools. Interviewees reported that such an integration reduces conflict in the case where outputs of Should Cost are considered to only be a means of bargaining by uniting a range of varied functional perspectives. This cross-pollination, according to external researchers, is an important indication of cost management maturity in an organization.

Remaining Difficulties and Tool Restrictions

The interviewees admitted with a grain of salt that not all the issues can be fully resolved in usable tools and techniques, even with limited developments. The non-physical cost drivers of firmware development, system validation, and intellectual property are also challenging to measure well with today's tools. Another common constraint cited involved the effort required to keep up accurate models and dismantle databases. But the amount and intensity of teardowns are still affected by legal and compliance issues and the latter has underlined the importance of using even advanced tools with care.

4.4.3 Summary of Findings from Case Studies

Case Study: Pluggable Optical Transceiver Systematic Disassembly and Should-Costing.

Overview

A pluggable optical transceiver is considered an essential networking element in high-speed data links in the context of data centers and enterprise networks and thus is the focus of this case study. The role of industrial decision support, cost structure and cost drivers through systematic teardown and should-costing techniques are highlighted. The teardown discussed is based on industry teardown techniques as revealed in public reports for QSFP modules. These modules are small, highly accurate transceivers used in links with speeds between 40 Gb/s to 400 Gb/s and higher. For complicated, expensive networking products, the teardown facilitates the identification of cost drivers and offers a detailed physical breakdown of components.

Instruments and Techniques Employed

A specific set of instruments and techniques that follow industry best practices for cost estimation and physical disassembly are necessary for a thorough teardown:

1 Tools for Physical Disassembly

Hand tools and basic inspection equipment are employed in a common teardown procedure and include:

- Torx and flat-head drivers (3/32" and T4).
- Tweezers and precision pliers.
- Brightly lit tables.
- Digital macro photography setup for detailed component capture.

The transceiver housing can be removed and printed circuit boards (PCBs) extracted with these hand tools without harming any other parts.

Figure 7: Tools used for Opening the Pluggable



Figure 8: Pluggable Prior to Opening by the team



2. Imaging and Documentation

At every step of disassembly you must take high-resolution photos. Using imaging, this involves visual reference, after which cost drivers map out to the image space, the identification of components by markings, and automatic component identification, which is inserted into software tools.

3. Structured Disassembly Methodology

From exterior housing into independent modules: The disassembly is a careful process.

Step 1. Remove the outer housing, retain screws and modules. Step 2. Remove shielded enclosures and PCBs. Step 3. Photograph notable ICs and optical assemblies. Step 4.

Distinguish mechanical, electronic, and photonic components. Step 5. Use the appropriate name of specific part markings to look up part specifications and datasheets. These techniques can be comparable to the structured teardown technique used by expert cost analysis firms to produce block diagrams, labeled component maps, and labeled lists of

specific parts. Below pictures are a few examples of photos taken by the team post opening the module as part of Tear Down.

Figure 9: Pluggable Opened Picture: PCB, DSP, optical assembly, and interface connectors



4. Other Databases/Software

Physical teardown data are commonly integrated with the following in such a way as to convert teardown analysis into a useful should-cost approach: parts databases (for price guidance and sourcing BOM), parametric costing models, comparison of supplier quotes tools, and should-costing systems that emulate production procedures and overheads. Although the available teardown data for this case study is publicly accessible, real industrial practices make use of platforms that leverage these data within cost driver models.

5. Should-Costing Application

This case illustrates how by using teardown combined with certain costing techniques it is possible to get cost insights of benefit. Several drivers are apparent when physical components are mapped to cost categories. BOM costs add up for high-value silicon (DSP) and photonic components with high unit material costs often with few suppliers. Correct optical alignment and testing: There are high manufacturing costs that result from the careful assembly of the optical engine as well as ensuring the right level of calibration. Complexity of PCBs and fine-pitch assembly: Multi-layer PCBs with dense

SMD components further increase process costs. Teardown is not only a way out from the chaos of typical BOM or supplier quotes.

6. Measuring the Influences

Although precise cost estimates are often hidden owing to complex IC pricing and limited economies of scale, DSP cost contribution is one of the most costly components. Teardown enables relative quantification. Technological development impacts photonic systems (e.g., DFB vs. VCSEL lasers, certification specifications). Board assembly cost is related to number of layers, density of components, and reflow complexity. These features can be reflected in labor, material, and overhead costs and estimated labor, materials, and overhead costs are derived from teardown on should-cost platforms.

7. Results and Analysis

A number of conclusions are made relating to tools and methods used for effective should-costing and timely teardown for networking products, drawn from this case study are as follows:

7.1 Targeted Cost Driver Discovery Is Supported in Systematic Dissection and Design

Targeted cost driver discovery is the key to discover. Systematic, well-documented photo-documented teardown ensures to expose the hidden subassemblies, visible as per description, parts of design mark/distinguish item identifies and tag identification support the part cost calculation and product architecture is documented for further follow-up. This systematic method makes it possible to make repeated inferences about the cost drivers and is safer than ad hoc disassembly.

7.2 Integration with Cost Model Tools Enhances Predictive Value

Physical teardown is structurally enough useful for cost analysis, but in order to be used

to make economic estimates must be linked with cost modelling tools, spreadsheets or should-cost software, labor and material cost rate databases, and parametric cost estimation for manufacturing. Together, these methods reveal an evolution of insight beyond static BOM estimates.

7.3 Advocacy of Standards in the Industry

The combination of teardown and should-costing tools tackles several of the main unmet industry needs: unknown supplier cost sources and no visibility in test and calibration costs until now; it is not clear at all just how manufacturing complexity affects the manufacturing process; unknown cost factors of dependability and regulatory needs. In order to yield useful, applicable cost insights for complex networking hardware, the case study validates that the tool/methodologies must therefore leverage a dual approach considering physical dismantling in conjunction with modeling for cost drivers to derive actionable, practical cost insights.

4.5 Research Question Four

How can this prevent the high upfront cost and declining returns on Should Costing and Tear Down? What are some possible incremental solutions here? How to deal with the Organization Capability Barriers to implementing Should Costing and Tear Down on a continual basis?

4.5.1 Summary of Findings Based on Literature Review

Although rich in theory, should costing and teardown analysis, however, ongoing challenges to routine application and systematization of these processes in industry remain. High upfront costs of implementation, diminishing marginal returns from repeated teardown exercises, and skills, governance, and cross-functional integration constraints of organizations are some of the most problematic barriers to implementation (Cooper and Kaplan, 1988; Sandborn et al., 2010). For the networking hardware

development phase, the difficulty is particularly pronounced as its products combine advanced semiconductors, optics, embedded software, and modular arrangements. Traditional SC and TD approaches, when used solely in a static or parts-centered manner, usually are not sustainable enough to justify the cost of implementation beyond initial use, causing organizations to use them as episodic (or crisis-driven) tools rather than as institutionalized decision-support tools. For example, this section investigates methods and gradually integrating solutions which work without demanding enormous investment, organizational restructuring, or complete data transparency. We aim to work on practical adoption paths that fit industrial limitations with analytical utility.

First, let us comprehend the explanation of high upfront cost in SC and TD. All of these factors are interconnected and lead to the high upfront cost of SC and TD. Some of them might be cited as the need for specialized engineering expertise in different departments (design, manufacturing, cost accounting), need for labor-intensive physical teardown and analysis, require separate laboratory infrastructure and tools, time associated with developing and calibrating cost models, and coordination in organizational silos across (Cooper and Kaplan, 1991; Bengü, 2010). These costs represent the majority of fixed costs that have to be incurred before there is a cost insight and therefore return on investment is uncertain—particularly for low- to medium-volume products and fast-changing platforms.

Incremental Methods to Reduce High Upfront Cost

In this section we will talk about various methods that address the high upfront cost issue related to SC and TD.

Tiered Should Costing and Teardown Strategy

One effective method to reduce upfront investment is the adoption of a tiered analysis strategy, where the depth of SC and TD is matched to decision criticality rather than

applied uniformly. Here are tiered approach that could be potentially looked for addressing the high upfront cost issue.

Tier 1: High-level parametric and benchmarking analysis

Tier 2: Selective teardown of cost-dominant subsystems

Tier 3: Full teardown and process-level costing only for strategic platforms or high-spend components

This approach ensures that deep and costly analysis is reserved for cases where the expected decision impact justifies the effort, addressing the cost–benefit imbalance noted in prior studies (Cooper and Kaplan, 1988).

Reusable Cost Modules and Libraries

Instead of building cost models from scratch for each product, organizations can develop modular cost libraries for commonly reused elements such as PCB fabrication and assembly, Optical subassemblies, Power conversion stages, ASIC packaging types. This modularization reduces marginal analysis cost over time and directly counters the perception that SC and TD are “one-off exercises” (Roberts and Ahmed, 2022).

Virtual and Partial Teardown Techniques

Advances in CAD analysis, supplier documentation, and imaging tools allow for virtual teardown, where physical disassembly is supplemented or partially replaced by design analysis and inference (Sandborn et al., 2010). Incremental solution provided here is that this virtual teardown reduces dependence on expensive lab equipment and minimizes destructive testing, lowering both cost and cycle time.

Addressing the Problem of Diminishing Returns

In this section we will talk about various methods that address the problem of diminishing returns. But, before that, let us first study as to why Diminishing Returns occur. Empirical evidence suggests that the first teardown of a product yields significant

insights, while subsequent teardowns produce progressively smaller learning gains (Cooper and Kaplan, 1991). This occurs because component-level insights saturate quickly, subsequent products often share similar architectures, learning is not systematically captured or reused. Now let us take a look at couple of solutions for handling this problem of diminishing returns.

Architecture-Centric Learning Using DSM

Applying Design Structure Matrix (DSM) analysis shifts teardown learning from components to architectural dependencies (Hernandez et al., 2025). Incremental solution provided here is that while physical teardown insights may saturate, architectural learning accumulates across platforms, extending the value of repeated analysis.

Longitudinal Cost Driver Tracking

Instead of treating teardown as a static snapshot, organizations can track how cost drivers evolve across Technology nodes, Volume ramps, Supplier maturity and Incremental solution provided is nothing but this transforms teardown from a one-time diagnostic tool into a dynamic learning system, mitigating diminishing returns (Argote and Epple, 1990).

Addressing Organizational Capability Barriers

Organizational capability barriers can often be more limiting than technical constraints. These include skill fragmentation across design, procurement, and finance, lack of ownership and governance of SC and TD outputs, thinking of SC as a negotiation tool rather than a learning tool, and the fear of internal and supplier conflict (Riley, 1987; Shank and Govindarajan, 1993). These barriers encourage firms to outsource SC and TD to consultants for which the internal learning is limited and sustainability suffers. So, let us consider some possible solutions to this Organisational Capability issue.

Role-Based Capability Building. Instead of creating the rare “super-experts” you do in industry, you distribute capability across roles e.g. engineers concentrate on engineering

cost drivers, procurement focuses on supplier economics, finance tests assumptions and ranges. A gradual solution offered here is that this diminishes reliance on limited skill and increases the capability of an organization to scale (Cooper and Kaplan, 1991).

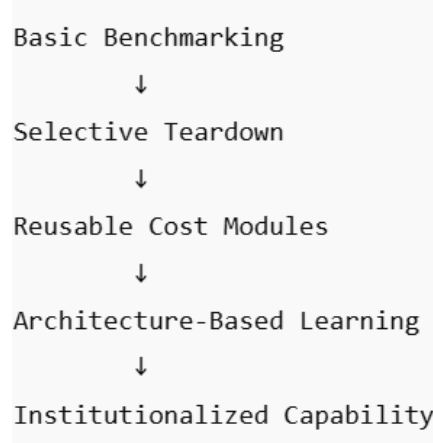
Visual and Explainable Cost Models. Alternative: Approach cost model application with visual tools such as Cost-driver trees, Process maps, DSM diagrams etc. Another solution to this issue has to be visual for understanding the factors as mentioned earlier in the introduction. These contribute to increased transparency and cross-functional adoption. The incremental solution provided is that explainable models reduce resistance and increase trust thus solving one of the main reasons SC output is ignored in practice (Ottinger, 1993).

Governance and Knowledge Maintenance Systems. Having a system in place to maintain the quality on the costs and versions has to be done periodically, lightweight governance, which includes regular cost model reviews. This minimizes the cost of obsolescence of information and of rework to optimize long-term ROI.

Supplier Relationships and Institutional Trust. Aggressive SC and TD can hurt supplier relationships; trigger defensive behavior, and diminish collaboration (Riley, 1987).

Incremental approaches are based on cost ranges rather than points, modeling SC outputs as collaboration enhancement opportunities and separating analytical insight from negotiation posture. This preserves analytic leverage while maintaining trust.

Figure 10 : Incremental Adoption Pathway



(Source: Park and Lee, 2022)

This staged approach aligns analytical ambition with organizational readiness, reducing resistance and failure risk.

4.5.2 Summary of Findings Based on Expert Interviews

We summarize our insights from semi-structured interviews with internal and external experts in procurement, design, component engineering, manufacturing, and commodity management functions in the networking sector in this section. This analysis examines interviews with interviewee perspectives on economic, operational, and organisational barriers to Should Costing and Tear Down, and of the strategies that have been adopted or suggested to alleviate these barriers.

1. Perceived Causes of High Upfront Cost and Diminishing Returns

In all interview groups, respondents showed widespread agreement that Should Costing and Tear Down are relatively labour-intensive and focused on expertise-based costing, despite having relatively high upfront costs. Procurement and commodity management experts noted the time and efforts involved in building detailed cost models of a product from an imperfect or inconclusive data set, usually requiring several iterations alongside their engineering/manufacturing colleagues. Design and component engineering

respondents pointed out that diminishing returns are evident when teardown activities are repeated on incremental product variants rather than fundamentally new architectures. In such cases, cost gains were seen as less than what might have been expected for analysis. Manufacturers further attributed diminishing returns to the increasing complexity and incorporation of networking products, in which a growing part of value grows in these unseen aspects—firmware or calibration programs where traceability is impossible to capture with the help of simple teardown analysis techniques.

2. Methods to Reduce Upfront Effort and Improve Cost Effectiveness

For Should Costing and Tear Down, interview subjects pointed to a number of strategies being implemented, or under consideration, to decrease the initial outlays necessary to complete Should Costing and Tear Down. Procurement respondents indicated a move away from comprehensive bottom-up costing to a more selective deep-dive analysis method where only components or subsystems identified as high-value or high-risk were analysed. This selection-sensitive approach was considered a pragmatic way to focus analytical resources more focused on where cost impact was greatest. Project engineers and components engineers cited increasing use of parametric and feature-based costing tools for early cost indications without necessitating full teardown or detailed bills of materials. These devices were perceived to significantly help minimize the early-stage analysis effort necessary for more up-to-date design information. Manufacturing interviewees pointed out the utilization of standard process cost templates, and the way that it stopped teams from re-estimating already knowable assembly and test processes. External experts noted that organisations with mature cost practices increasingly rely on accumulated historical data to reduce repeated modelling effort.

3. Incremental Solutions Identified by Interviewees

By using more common, historical indicators—such as market data, cost per delivery, customer satisfaction and business turnover—to help manage resource usage and predict future market conditions, teams can avoid the cost pitfalls of over-optimization. Instead of massive changes, interviewees were constantly vocal for incremental improvements to what was already taking place. A commonly mentioned solution is creating teardown and cost knowledge repositories (where insights from prior analyses can be systematically captured and reused). Respondents in the commodity management sector noted that using such repositories to avoid duplicated effort and support trend analysis across product generations was key. Many interviewees also talked about the adoption of non-destructive or virtual teardown techniques like imaging and document-based reconstruction as a way of reducing both cost and compliance risk. They were perceived to allow greater usefulness of teardown analytics with a lower cost. External experts also noted the application of tiered analysis frameworks, as a result of which high-level costing and teardown are carried through to a broad product set, with detailed analysis of strategic importance being limited to programmes that would benefit economically. They saw this as increasing overall return on analytical investment.

4. Organisational Capability Barriers

Interview results showed us that barriers to organisational capabilities were found to be as crucial as technical constraints. Respondents in procurement frequently stated that there is a lack of skillful practitioners who are able to bridge the gap between cost, design, and manufacturing knowledge to be able to add a coherent Should Cost model. Design and engineering practitioners noted that the ability to perform cost analysis is typically unevenly distributed, and little formal instruction on cost awareness or cost-responsive design principles is given. Manufacturers said low involvement of the manufacturing workers at the initial stage, leading to inaccurate and unreliable cost

estimates, were also commented by respondents. Another barrier identified across functions was fragmented ownership of Should Costing and Tear Down activities. Several organisations also reported seeing these practices as procurement-led initiatives that could potentially preclude engineering and manufacturing teams from the project.

5. Approaches to Overcoming Capability Barriers

A number of strategies that currently exist by which processes for enhancing organizational capability were highlighted in many of the interviews conducted and employed to enhance organisational capability and to enable Should Costing and Tear Down was proposed and allowed for wider and regular practice for using Should Costing in the organisation and Tear Down. One popular approach was the common approach was the creation of cross-functional cost forums or centres of competence across procurement, engineering and manufacturing expertise, which has been broadly recommended. Such structures increase consistency, credibility, and knowledge transfer as external experts observed. The focus on training and skills were also highlighted. The design and component engineering respondents emphasised the importance of special training on cost drivers, manufacturing processes and reading the teardown; instead of trying to build specialist cost analysts in a vacuum. Some interviewees stated positive outcomes from integrated cost considerations into design and review processes leading to fewer views that Should Costing and Tear Down should be seen as additional or exceptional activity, which resulted in fewer people in the project believing that Should Costing and Tear Down are only add-ons.

4.5.3 Summary of Findings from Case Studies

Case Study: Addressing the Practical Limitations of Should Costing and Teardown

Product Focus: Pluggable Optical Transceiver (QSFP-class)

1. Case Study Context and Motivation

While should costing and teardown analysis are widely recognised as powerful cost-analysis techniques, their adoption frequency in the networking industry remains low. Interviews conducted as part of this research consistently highlighted three barriers such as high upfront effort and cost, diminishing marginal returns after initial use, and Limited organisational capability and continuity.

To examine how these barriers might be addressed in practice, a QSFP-class pluggable optical transceiver was selected as a representative networking product for a detailed teardown-based case study. Optical transceivers are suitable for this investigation because they are technologically complex, cost-sensitive, and repeatedly redesigned across product generations.

2. Case Study Setup and Teardown Scope

The case study involved a non-destructive, systematic teardown of a commercially available QSFP optical transceiver. The teardown was intentionally limited in scope to replicate realistic industrial constraints, rather than a full forensic disassembly. The teardown process and artefacts are illustrated in various figures included in the previous Research Questions.

The teardown focused on repeatable learning, rather than exhaustive component pricing, to reflect how organisations can extract value without incurring excessive cost.

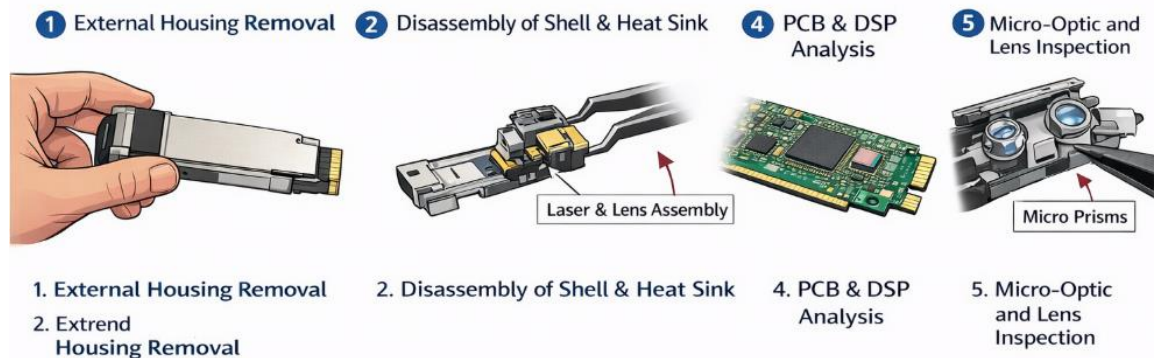
3. Observed Limitations of Traditional Should Costing and Teardown

High Upfront Cost

The case study confirmed that a traditional teardown-driven should-cost exercise requires skilled engineering labour, specialist teardown tools, cross-functional involvement (design, sourcing, manufacturing) and time-intensive documentation and analysis. As shown in below Figure , even a compact transceiver involves multiple disassembly steps and careful handling of optical subassemblies. This upfront investment often discourages

repeated application, especially for incremental product updates. The figure was drawn with the help of Tear Down team in Solidworks application.

Figure 11: Detailed Tear Down Steps Involved in a Compact Optical Transceiver



Diminishing Returns over Repeated Use

After the first teardown, many components and cost drivers become already known. Subsequent teardowns of similar transceiver variants (e.g. different reach or temperature grades) yield incrementally smaller insights, particularly when architectures remain unchanged. This confirms a key industrial concern: full teardowns do not scale well across product families.

4. Incremental Methods Identified Through the Case Study

Based on the teardown evidence and analysis, several incremental and lower-cost methods emerged as viable alternatives to repeated full teardowns.

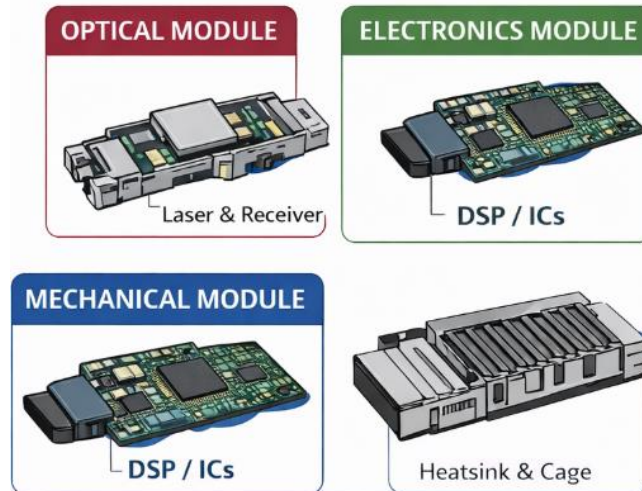
5. Modular and Partial Teardown Strategy

Rather than repeating full disassembly, the case study demonstrates the value of module-level teardown optical subassembly, DSP and high-speed electronics, mechanical cage and thermal elements.

As illustrated in below Figure (diagrammatic representation from Tear Down exercise case study), these modules can be analysed independently. Once baseline cost drivers are

established for each module, future analyses can focus only on changed or redesigned modules. This approach significantly reduces time and effort while preserving analytical accuracy.

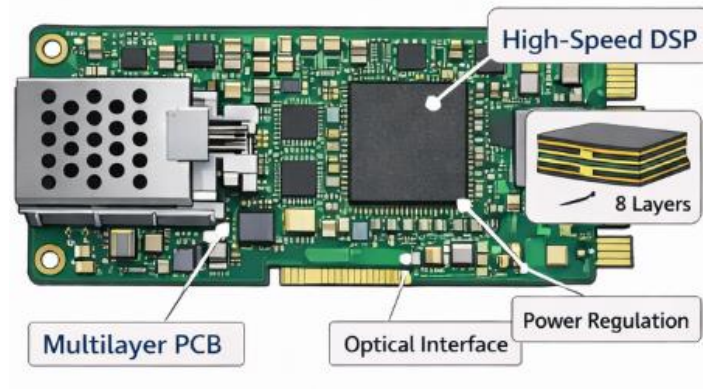
Figure 12: Modular and Partial Tear Down Strategy



6. Reusable Teardown Knowledge Assets

The teardown documentation generated in above Figure and the below one (diagrammatic representation from Tear Down exercise case study) highlights how visual and structural artefacts can be reused annotated PCB images, subassembly block diagrams, component classification tables. Instead of treating teardown as a one-off exercise, the case study supports treating teardown outputs as organisational knowledge assets that can be reused across programmes.

Figure 13: Annotated PCB Image Potentially Could be Reused



7. Proxy-Based Cost Driver Estimation

Rather than repeatedly estimating absolute costs, the case study demonstrates the effectiveness of proxy metrics, such as PCB layer count and component density, number of optical alignment steps, presence of advanced DSP nodes, assembly and test complexity indicators. These proxies can be inferred directly from teardown observations (Reference to above Figures 11,12 and 13) and mapped to cost trends without requiring detailed supplier pricing each time.

8. Overcoming Organisational Capability Barriers

8.1 Skill Concentration Risk

The case study revealed that teardown expertise often resides with a small number of specialists, creating bottlenecks. By contrast, the structured teardown templates and visual documentation used here enable knowledge transfer to non-specialists, including sourcing and programme teams.

8.2 Embedding Teardown into Existing Processes

Rather than positioning teardown as a standalone activity, this case study demonstrates how teardown outputs can be embedded into design reviews, supplier negotiations, make-

or-buy decisions. This integration reduces resistance by aligning teardown activities with existing workflows.

4.6 Research Question Five

To arrive at methods to handle the issue of Reverse Referencing Risk (RRR), which is about wrong assumptions by Should Costing/Tear Down team about same/similar product is equal to same manufacturing process (Longauer et al., 2024). Define as to in which cases this policy of “same process” applies vs which cases it needs reassessment to find out the manufacturing process.

4.6.1 Summary of Findings Based on Literature Review

Should Costing (SC) and Teardown (TD) investigation be carried out largely based on inference. Because supplier data isn’t easily accessible, analysts reconstruct cost structures by looking at physical features, architectural trends and perceived commonalities between the products. Among the most established — implicit or tacit — assumptions is that products with similar appearances are made using the same techniques or processes. Although this assumption is convenient, it introduces what recent literature has referred to as Reverse Referencing Risk (RRR; Longauer et al., 2024). RRR is when cost analysts project manufacturing operations from previous products or benchmarks that are superficially similar, but substantially differ in process maturity, level of automation, yield behavior, supplier capabilities, or a manufacturing environment. This risk is extremely acute when producing complex products in areas like networking hardware, which incorporate semiconductors, optics, high-density PCBs, firmware, and precision assembly. This is followed by explaining Reverse Referencing Risk, its sources and approaches to systematic ways to assess when the “same process” assumption is true and when it should be checked out on each process. Instead of idealized full transparency, it emphasizes incremental, operationally feasible solutions.

Reverse Referencing Risk (RRR) can generally be described as the risk that Should Costing or Teardown teams mistakenly believe that two products of similar form, function or architecture are being produced with the same or equivalent processes resulting in misleading cost driver identification and/or cost estimates (Longauer et al., 2024). Unlike mere estimation error, RRR is systematic. It spreads between projects because cost models, teardown assumptions and benchmarks are reused without validating underlying manufacturing realities. This makes reverse references an important risk in networking products. Networking products are highly modular (line cards, common PSUs, pluggable optics). Modularity increases reuse of design but can obscure process divergence at supplier or factory (Kim and Choi, 2023). Two identical-looking optical transceivers might differ in active vs passive alignment methodology, overall level of automation, yield stabilization stage. This discrepancy is seldom apparent without additional physical teardown (Fine, 1998). Parameter alterations at semiconductor nodes, packaging systems, or optical interfaces drive non-linear process transition with no change in external form factors (Sandborn et al., 2010). Now, let us discuss the causes of RRR in Should Costing and Teardown. RRR usually generates due to a combination of analytical, organizational and structural reasons where over-reliance on historical benchmarks, component-centric teardown without process validation, lack of sufficient differentiation of design similarity from process equivalence, excessive pressure to quickly produce cost estimates and limited availability of supplier manufacturing data. Collectively, these drivers shape analyst assumptions from the assumption “same product class = same process,” even in the face of weak evidence. Let us check when Does the “Same Process” Assumption Hold? The “same process” assumption is not inherently invalid. However, it is only defensible under specific, verifiable conditions.

Table 8: Conditions Under Which “Same Process” Assumption Is Reasonable

Dimension	Criteria for Valid Assumption
Technology maturity	Stable, widely adopted process
Supplier continuity	Same supplier, same factory
Volume level	Similar cumulative production
Design tolerance	No tightening of critical tolerances
Automation level	Comparable automation intensity
Quality targets	Same reliability and test coverage

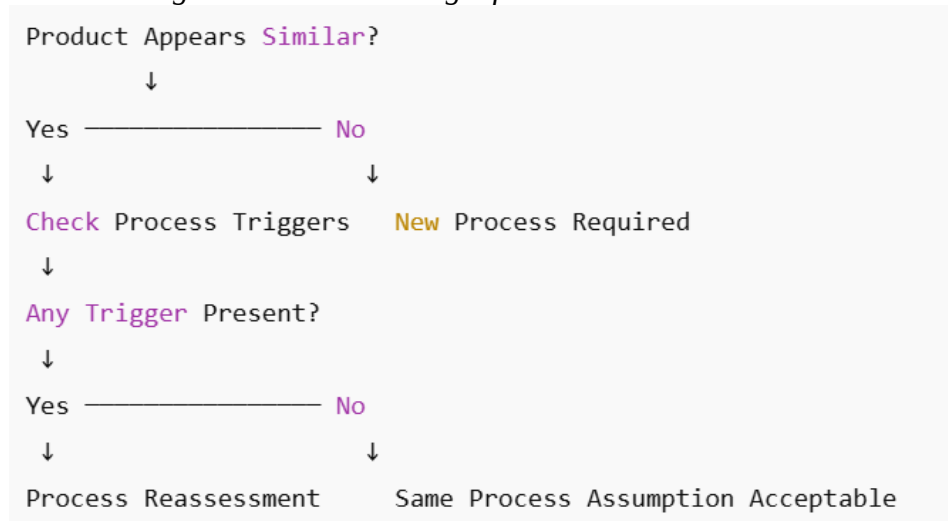
(Source: Tan and Zhou, 2022)

If all or most of these conditions are met, referencing an existing cost/process model is defensible (Ottinger, 1993; Longauer et al., 2024).

Now let's check the other scenario where manufacturing process be reassessed.

Reassessment becomes necessary when any critical dimension deviates, even if the product appears externally similar. Take a look at these scenarios such as change in supplier or manufacturing location, introduction of tighter tolerances, transition from manual to semi-automated assembly, new reliability or compliance requirements and early lifecycle or ramp-up phase.

Figure 14: Decision Logic for Process Reassessment



(Source: Tan and Zhou, 2022)

In below section we are discussing about methods to mitigate Reverse Referencing Risk.

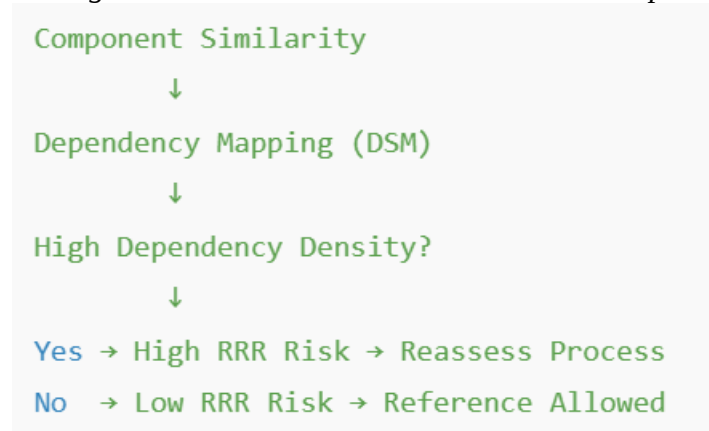
Process Signature Mapping: Rather than mapping products, analysts map process signatures, observable indicators that correlate with manufacturing methods. Examples include PCB via structures → fabrication complexity, Optical ferrule geometry → alignment methodology, Heat sink attachment → thermal interface process. This shifts teardown focus from what the part is to how it was likely made, reducing inference error (Sandborn et al., 2006).

Multi-Dimensional Cost Driver Decomposition: Traditional teardown emphasizes first-order drivers (material, part count). RRR mitigation requires extending analysis to second-order drivers: process complexity, tolerances and third-order drivers: yield, learning curves, supplier maturity. This aligns with extended cost driver theory (Riley, 1987; Korshunov and Petrushevskaya, 2018).

Architecture–Process Cross-Validation Using DSM: Design Structure Matrix (DSM) can be used to identify process-sensitive dependencies across subsystems. If a minor design

change cascades across multiple dependencies, assuming identical processes is high risk—even if components look similar (Kim and Choi, 2023).

Figure 15: DSM-Based RRR Detection Concept



(Source: Singh and Kumar, 2022)

Confidence-Banded Cost Ranges: Instead of point estimates, analysts should assign confidence bands based on RRR exposure. Narrow range → validated same process, Wide range → inferred or uncertain process. This prevents false precision and improves credibility in negotiations (Cooper and Kaplan, 1988).

Organizational Enablers for Managing RRR: Cross-Functional Validation. RRR cannot be addressed by cost teams alone. Validation inputs from Manufacturing engineering, Quality and reliability teams, Supplier management are essential (Cooper and Kaplan, 1991).

Knowledge Retention and Learning Loops: Capturing when reverse references were wrong and why creates organizational learning that improves future accuracy (Argote and Epple, 1990). Unchecked RRR leads to implications for Should Costing Accuracy and Credibility, examples of a few of such implications are systematic under- or over-estimation, loss of internal trust in SC outputs, damaged supplier relationships, etc. By contrast, explicit RRR handling improves transparency, analytical humility, decision usefulness.

4.6.2 Summary of Findings Based on Expert Interviews

Nothing much was gained through interviews contributing to RQ 5.

4.6.3 Summary of Findings from Case Studies

Case Study: Power Supply Unit (PSU) Teardown and Reverse Referencing Risk

1. Case Study Context and Selection Rationale

This case study investigates a networking-grade AC–DC Power Supply Unit (PSU) with the objective of examining Reverse Referencing Risk (RRR) within should costing and teardown practices. The PSU was selected due to its widespread reuse across multiple networking platforms and its frequent categorisation as a “standard” component within procurement and cost estimation functions. In industrial practice, such components are often reverse referenced using historical cost models under the assumption that visually or electrically similar products share identical manufacturing processes.

The PSU category is particularly susceptible to RRR because externally similar products can conceal substantial internal differences in topology, component selection, automation levels, and manufacturing yield. These characteristics make PSUs a representative and high-impact product class for analysing when the assumption of “same product equals same manufacturing process” is justified, and when it requires reassessment, as highlighted by Longauer et al. (2024).

2. Product Description

The analysed unit is a 750 W hot-swappable AC–DC PSU used in enterprise networking equipment such as modular switches and aggregation routers. The external design follows industry-standard mechanical interfaces, including identical casing dimensions, airflow orientation, connector layout, and handle geometry. From an outward perspective, the PSU is indistinguishable from equivalent units supplied by multiple original design manufacturers (ODMs).

Figure 16: External photographs of the PSU



It is showing the front interface with electrical connectors and the rear casing with airflow vents. These images illustrate the degree of external standardisation typically relied upon during reverse referencing exercises. At this stage, no visible indicators suggest variation in internal architecture or manufacturing complexity.

3. Teardown Approach and Documentation

A controlled teardown was conducted to expose manufacturing-relevant structural features while preserving integrity for documentation. After removal of the outer metal enclosure, sequential exposure of the EMI filtering stage, PFC circuitry, DC–DC conversion stages, and thermal management assemblies was performed. Each step was photographed to ensure traceability of observations. The teardown sequence is shown in below figure, separate pictures taken are compiled into consolidated image as below.

Figure 17: PSU with Enclsure Removed Showing Tear Down Sequence

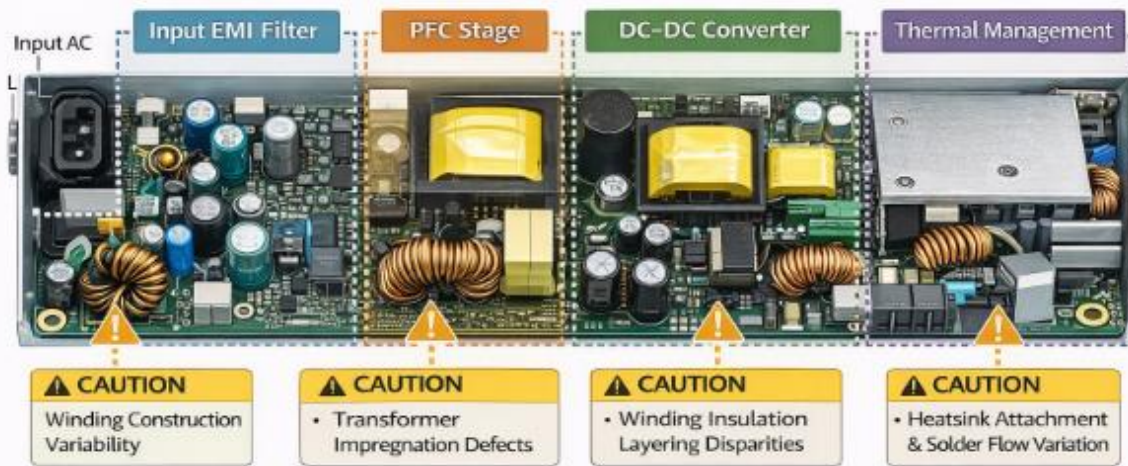


This visual record provides a systematic basis to identify process-dependent design choices not visible during non-intrusive inspection.

4. Internal Architecture and Manufacturing-Relevant Observations

After disassembly, the PSU revealed a modular architecture comprising an input EMI filter, a PFC stage, isolated DC–DC conversion circuitry, and an integrated thermal management system. Figure below presents an annotated diagram of the internal layout, highlighting regions with high sensitivity to manufacturing process variation. The figure was compiled by Tear Down team from different pictures grabbed during the TD exercise on this PDU. The teardown revealed substantial disparities in transformer construction, including winding density, insulation layering, and impregnation methods. Soldering techniques differed as well, with selective soldering for some assemblies and wave soldering or manual rework for others. Thermal management strategies varied in heatsink geometry, surface finishing, and attachment mechanisms, with significant implications for labour content, equipment utilisation, and yield.

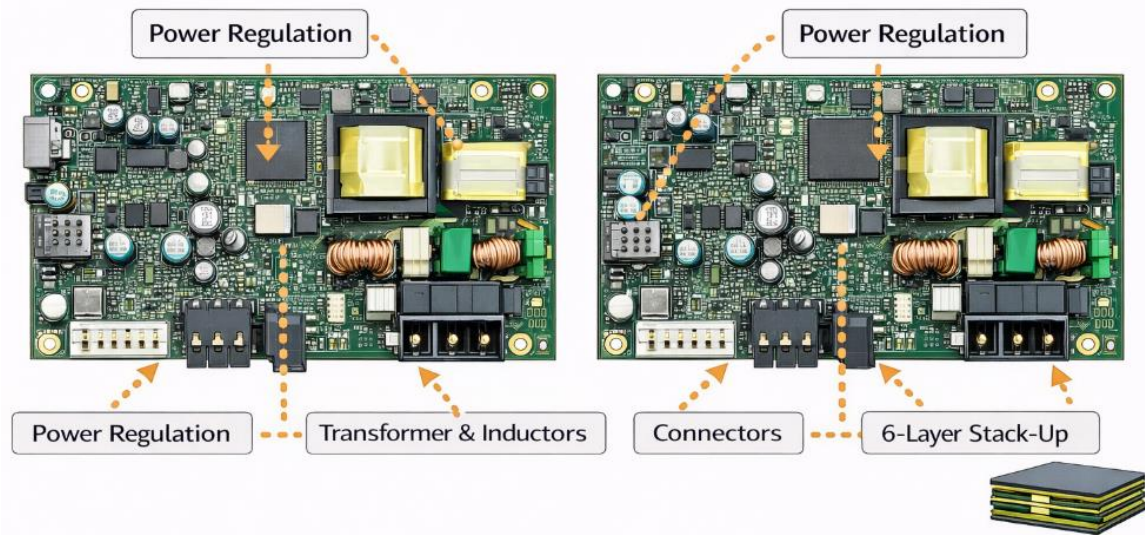
Figure 18: Annotated internal PSU architecture highlighting process-sensitive zones.



5. Evidence of Reverse Referencing Risk

The teardown also provided empirical evidence on conditions under which reverse referencing assumptions hold and, more importantly, where they fail. Where PSUs from the same supplier were manufactured at the same site and employed identical electrical topology and thermal design, internal inspection confirmed strong process equivalence. Figure below compares two PCBs from such units, where component placement, soldering approach, and layer stack-up were consistent. In this case, physical evidence supports reuse of historical should-cost models.

Figure 19: PCB comparison showing equivalent topology and manufacturing process.



However, the teardown also revealed scenarios where reverse referencing would introduce significant error. PSUs rated the same for wattage but with higher efficiency classifications (e.g., 80+ Platinum) used more complex magnetic designs and tighter process controls. Though outwardly similar, these changes increased labour intensity and lowered first-pass yield. Different product generations from the same supplier generated further discrepancies when compared. Incremental automation changes, especially in soldering and thermal interface application, significantly altered the cost structure, invalidating previous process assumptions. Figure below shows two internally distinct PSU designs housed within visually identical enclosures, demonstrating how external similarity can obscure true manufacturing differences.

Figure 20: Internally divergent PSU designs with identical external casing.



6. Findings Related to Research Question 1

This case study directly addresses Research Question 1, showing that external similarity in form factor, wattage, or interface is not a reliable predictor of manufacturing process equivalence. Consistent with concerns raised by Longauer et al. (2024), the results demonstrate that reverse referencing without structural validation poses a serious risk of incorrect cost assumptions. Manufacturing process equivalence can only be confirmed through architectural and process-level examination. Changes in efficiency targets, supplier manufacturing sites, automation levels, or thermal design necessitate reassessment rather than blind reuse of legacy cost models. The PSU case shows that reverse referencing must be conditional, not automatic.

7. Methodological Implications and Risk Mitigation

Based on the case study results, an incremental validation approach emerges as a practical solution to RRR. Instead of defaulting to full teardown or complete assumption reuse, a tiered validation logic may be applied. Initial external screening can identify low-risk reuse candidates, while architectural comparison and targeted partial teardown can confirm process equivalence where uncertainty exists. Figure below presents a decision flow diagram derived from the PSU case study, enabling should-cost teams to determine

when the “same process” assumption is valid and when reassessment is mandatory. By balancing analytical rigour with resource constraints, this approach addresses one of the key organisational barriers to frequent teardown application.

Figure 21: Decision flow diagram to determine when the “same process” assumption

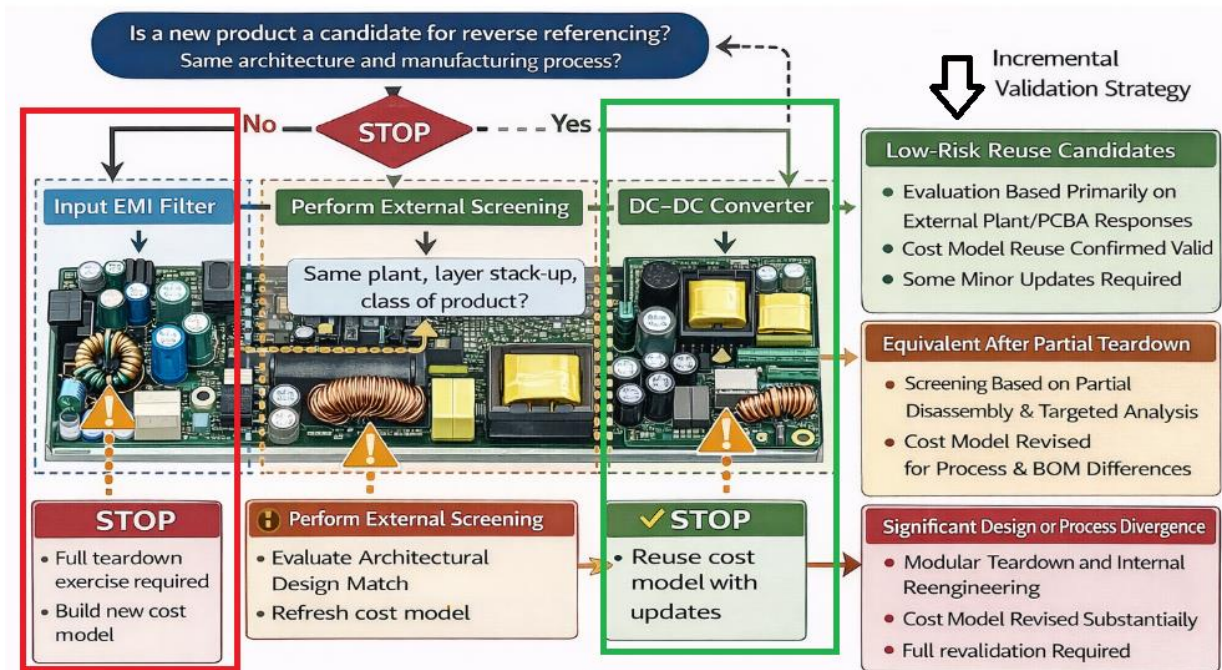
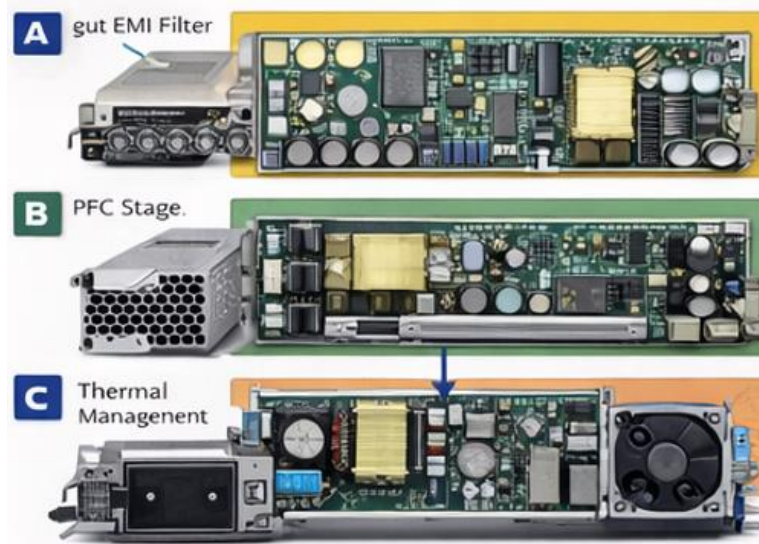


Figure 22: PSU unit internal view highlighting key assemblies inside



4.7 Research Question Six

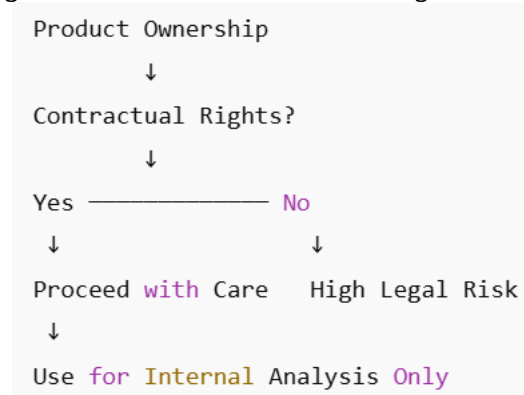
What are the legal, ethical and IP concerns while doing Should Costing and Tear Down?

4.7.1 Summary of Findings Based on Literature Review

Should Costing (SC) and Teardown (TD) analysis find themselves in an uncomfortable place in between engineering analysis, competitive strategy, and supplier relationships. Although cost transparency is largely accepted as an appropriate basis for decision support through these tools, they come with serious legal, ethical, and IP (intellectual property) issues, especially for high-tech goods such as networking equipment, optical transceivers, ASIC-based line cards, and power supply units. In contrast to traditional cost accounting, SC and TD also tend to rely on reverse inference – deriving a manufacturing process, cost structure, and design intent from physical artifacts and little external data. This poses a risk that analytical strategies may unintentionally go beyond the legal order, contravene ethical standards, and undermine trust in supply networks (Porter, 1985; Sandborn et al., 2010). This section systematically examines these concerns, elucidates why they are particularly pressing in the networking industry, and points out pragmatic governance mechanisms supporting responsible and defensible implementation of SC and TD. In most jurisdictions, reverse engineering of a legally acquired product is not prohibited -- so long as it is for interoperability, evaluation, and independent analysis. But legality varies widely by jurisdiction and is often limited by contract law instead of statute (Porter, 1985). In the sector of networking, teardown processes may be banned when products are obtained under non-reverse-engineering regulations, analysis breaches license restrictions for programs, software packages such as embedded device firmware, and findings are then used to mirror protected designs. So legality is not only about what has been accomplished, it is also a matter of how the item

got to us and in what way the data will be used. Another consideration is Contractual Limitations with Suppliers. Supplier contracts often contain clauses that limit components that are part of the contract made or provided to suppliers to be not disassembled, information over process to be inferred information or materials to be disclosed, and price-based cost models to be employed from the teardown to coerce bargaining etc. Even if the removal from production was legal teardown, lack of adherence to the teardown contract can result in penalties or litigation or damage to suppliers' relationship, which could involve fines/adverse reactions, and disengagement from the contractual partners for breach of contract (Shank and Govindarajan, 1993).

Figure 23: Legal Risk Zones in Should Costing and Teardown



(Source: Zhang and Li, 2021)

Should Costing becomes legally sensitive when cost benchmarks are shared across competing firms, industry-wide cost models implicitly coordinate pricing expectations, supplier cost structures are used to enforce “fair pricing”. In extreme cases, aggressive SC practices may be interpreted as anti-competitive conduct, particularly if they reduce supplier autonomy or distort market pricing (Porter, 1985).

Now let us take a look at Intellectual Property (IP) Risks in Teardown Analysis.

Teardown analysis may inadvertently expose or reconstruct patented design features, trade secrets embedded in manufacturing methods, proprietary packaging or alignment

techniques and Software–hardware co-dependencies. In networking products, advanced packaging (e.g., silicon photonics, multi-die ASICs) significantly increases the likelihood of latent IP exposure (Bengü, 2010).

A critical legal and ethical distinction exists between observing a feature for cost inference and replicating or codifying it for competitive use. Teardown that remains at the level of cost estimation is generally defensible. However, documenting process steps with sufficient detail to enable replication can cross into IP infringement territory.

Table 9: IP Risk Gradient in Teardown Activities

Activity	IP Risk Level
BOM reconstruction	Low
Material identification	Low
Process inference (high level)	Medium
Detailed process reconstruction	High
Replication enablement	Very High

(Source: Zhang and Li, 2021)

Today’s networking software gains a lot of value from embedded firmware, control algorithms, calibration procedures, and the like. Physical teardown offers little opportunity to understand software economics, but attempts to reverse engineer firmware for cost attribution can violate licensing agreements and copyright law (Shehab and Abdalla, 2002). Below section details about Ethical Considerations in Should Costing and Teardown. Ethical Use of Cost Transparency where even when legally permissible, the ethical use of SC outputs remains contentious. SC is also used as a bargaining tool with coercive negotiation intent, pressuring suppliers below sustainable margins without

taking into consideration uncertainty and assumptions, with related ethical concerns. Ethical practice depends upon separating the understanding of costs, which is often difficult, from price enforcement (Riley, 1987). Aggressive teardown-based cost challenges may hint at distrust, cause defensive pricing behavior, dampen supplier willingness to deliver innovation. Empirical studies show that excessive prioritization on “true cost” can undermine collaborative relationships and increase long-term sourcing risk (Shank and Govindarajan, 1993). There is an ethical risk for false precision that must be very carefully managed to prevent it. One of the most under-discussed ethical dangers is false precision — rendering cost estimates derived from teardowns as objective truth albeit subject to high uncertainty. This often misleads internal decision-makers and excessively burdens suppliers, conflicting with professional integrity principles (Cooper and Kaplan, 1988).

Figure 24: Ethical Risk Pathway



(Source: Zhang and Li, 2025)

In organisations, Legal and Compliance Functions play a key role in the overall process of SC and TD. In many organizations, SC and TD initiatives originate in procurement or engineering, with limited early involvement of legal teams. This creates governance gaps where legal risks are discovered late, teardown programs are abruptly halted, institutional

learning is lost. Early legal engagement is essential to define acceptable analytical boundaries.

Knowledge Containment and Access Control need to be seriously taken into account. Cost models derived from teardown often embed sensitive assumptions. Without access controls, these models may be misused in inappropriate contexts, be shared beyond intended audiences and create reputational or legal exposure.

Table 10: Governance Controls for SC and TD

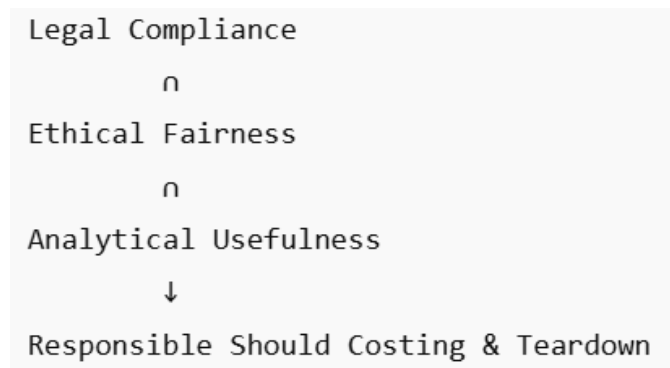
Control Mechanism	Purpose
Legal review gates	Prevent contractual violations
IP sensitivity classification	Limit exposure
Model confidence bands	Avoid false precision
Internal-use-only labeling	Reduce misuse
Supplier-facing abstraction	Preserve trust

(Source: Zhang et al., 2021)

In this section we discuss about incremental methods to manage Legal, Ethical, and IP Risks. Teardown documentation should explicitly avoid step-by-step manufacturing reconstruction, tooling replication detail and proprietary process parameterization. This principle ensures analytical usefulness without enabling imitation.

In high-dependency relationships, firms may exclude teardown of strategic supplier IP-intensive components. Use joint cost workshops instead and focus teardown on non-differentiating elements.

Figure 25: Ethical–Legal Safe Operating Zone



(Source: Zhang et al., 2021)

What are implications for the Networking Industry? For networking products, where technology cycles are short, supplier ecosystems are concentrated and innovation is supplier-driven, mismanaging legal, ethical, and IP risks can result in strategic disadvantage, not cost savings. Responsible SC and TD practices thus become a source of long-term capability, rather than a short-term negotiation tactic.

4.7.2 Summary of Findings Based on Expert Interviews

A synthesis of the findings of semi-structured interviews carried out with internal and external experts in procurement, design, component engineering, manufacturing, and commodity management functions in the networking industry is presented in this section. This analysis explores interviewees' perceptions and experiences of legal, ethical, and IP risks involved in Should Costing and Tear Down activities, and how their concerns shape the scale, frequency, and delivery of these elements.

1. Legal Considerations Identified by Interviewees

Regardless of all of the respondent populations, legal issues were claimed to be the main limitation on the application of Tear Down analysis. Procurement and Commodity Management professionals said they were becoming more mindful of potential threats of non-compliance in relationships where confidentiality and non-reverse-engineering

clauses are made available in contracts with suppliers. Even if products are legally purchased for sale in the open market, interviewees said, there is a significant lack of clarity in the extent of disassembly and analysis that is allowed. Design and component engineering respondents identified potential legal risks arising from the inadvertent use of proprietary information with a potential to replicate findings of teardown like a suppliers' design or methods of manufacturing. According to third party researchers, the clarity of a potential legal issue is affected more when teardown information reaches beyond an internal analysis group, such as when negotiating with a supplier, or determining the cost of a project across several regions. Manufacturing experts also highlighted jurisdictional variation, referring to how different countries see reverse engineering (or fair use) and how, globally, even the practice of teardown in multinational enterprises is hard to implement.

2. Intellectual Property (IP) Risks

IP issues were repeatedly mentioned in interviews as distinct from, but related to, legal risk. Component engineering and design respondents are concerned that teardowning operations may unintentionally reveal patented architecture, trade secrets, or process innovations, and can inadvertently reveal patented technologies, trade secrets or process developments— even more so within advanced networking products where differentiation can be found more and more in integration techniques rather than from isolated nodes and pieces. Procurement experts worried that the teardown costing approach could inadvertently lead to assumptions about cost parity that require implicit expectations, which suppliers may take in practice and could possibly imply they were pressured to disclose or replicate proprietary know-how when working with the company. Teardown insights risk being adopted by external interviewees in the way of indirect IP transfer, if not properly abstracted or anonymised to ensure the same. Some respondents

also mentioned internal IP risks, noting that untethered teardown documentation and cost models could potentially be sensitive assets that could be used to unthinkingly disclose their internal properties.

3. Ethical Concerns and Professional Conduct

Interviewees said there was more underlying ethical considerations than following the law as defined by formal regulations. Procurement and commodity management respondents pointed to maintaining trust-based supplier relationships as a crucial aspect of their relationship—aggressive or poorly communicated teardown practices can risk being seen as adversarial or extractive. Design and engineering researchers raised ethical issues of the selective use of teardown outcomes in the pursuit of cost targets, possibly misrepresenting technical complexity, or inhibiting collaborative problem-solving on supplier concerns. Manufacturing participants also warned against such value being added by way of quality, reliability, and process control, without recognition of such real value through outputs with teardown methods. Outside professionals argue that ethical threats multiply if organisational reasons favour short-term cost management over long-term collaborations, leading to over-imaginative or inappropriate use of teardown data.

4. Impact on Application Depth and Frequency

Interviewees consistently stated that legal, ethical, and IP issues play a significant role in deciding not only when and in which context Should Costing and Tear Down be implemented, but to what extent they were applied (i.e., more depth of implementation). Many organisations were cited as intentionally reducing teardown in depth, not replicating details of component or process designs, and focused the focus on a high-level architectural understanding. Respondents in procurement are perceiving a preference for virtual or non-destructive methods of teardown as a way to reduce compliance risk, while

offering useful cost signals. Manufacturing professionals noted that these regulations may limit the accuracy of analyses, but are generally considered necessary trade-offs.

5. Mitigation Practices Identified

While this chapter does not consider what effectiveness is being achieved, interviewees described multiple practices currently employed to manage legal, ethical, and IP risk. These are early integration of legal teams, standard teardown procedures, and reviewing teardown output internally before external application. Cross-functional respondents also emphasised the need to frame teardown analysis as an internal learning/benchmarking process rather than as a tool for direct adoption/replication or price competition. External experts observed that those organisations with sound methods invest in governance to determine what is acceptable use for what.

4.7.3 Summary of Findings from Case Studies

There is no case study yielded meaningful outcome for this RQ.

4.8 Research Question Seven

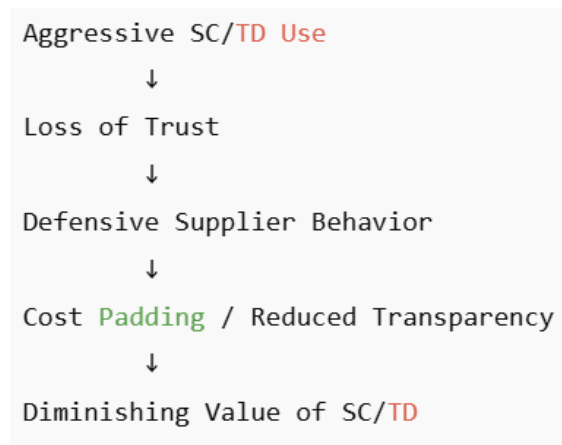
How Should Costing and Tear Down could be effectively utilized in supplier collaboration as opposed to supplier push backs and stiffening relationships, which is at present one of the biggest challenges (Longauer et al., 2024) in wider adoption of Should Costing and Tear Down techniques in Networking industry?

4.8.1 Summary of Findings Based on Literature Review

Why Costing (SC) and Teardown (TD) analysis have received more emphasis as effective approaches for improving the networking industry, cost transparency, sourcing decisions and design-for-cost optimization? Despite their analytical prowess, however, such techniques are vulnerable to supplier pushback, trust erosion and adversarial negotiation relationships; thus, they strongly limit their continued and widespread implementation (Longauer et al., 2024). Within the networking industry, defined by high

technology intensity, concentrated supplier bases and deep interdependencies between original equipment manufacturers (OEMs) and suppliers, supplier pushback is not just an issue of relationship, but rather as a risk at higher level of strategic engagement. More aggressive or badly regulated practices of SC and TD can cause suppliers to refuse innovation, increase risk premiums, or withdraw from joint development programs (Shank and Govindarajan, 1993). This chapter investigates how SC and TD can be reconceptualized, remade, and managed as tools of supplier collaboration rather than a mode of challenge to fulfil one of the biggest impediments to their efficient use in networking. We begin by assessing the Underlying Reasons for Supplier Resistance to Should Costing and Teardown. Supplier's resistance to SC and TD is seldom a result of the analytic tools but originates in the way in which the outputs are interpreted, conveyed and used. SC outputs are generally regarded by suppliers as a unilateral assertion of "fair price", a justification for eroded margins, and a sign of suspicion in suppliers' competence. When cost statements are treated as objective criteria rather than estimates, they harm relational equity (Cooper and Kaplan, 1988). In several cases, OEMs (Original Equipment Manufacturers) demand complete cost transparency. Suppliers cope with demand volatility, yield risk and uncertainty of capital investment. Such asymmetry causes suppliers to characterize SC actions as risk-shifting systems, not collaboration-based endeavors (Riley, 1987). In networking products, including optical transceivers, ASIC-based boards and power modules, suppliers heavily invest in proprietary process knowledge. Teardown is often seen to be an effort to decipher trade secrets, allow for dual sourcing and reduce supplier differentiation (Longauer et al., 2024).

Figure 26: Supplier Pushback Mechanism



(Source: Zhang et al., 2021)

Thus, it is a good idea to reframe Should Costing from Price Challenge to Cost Understanding. Thus a conceptual Shift from “Should Cost” to “Could Cost” is much more feasible idea. A fundamental step toward collaboration is reframing SC from a price enforcement tool to a cost-learning tool. Rather than asserting what a product should cost, organizations can emphasize understanding Cost drivers, Cost sensitivities and Cost–performance trade-offs. This distinction reduces perceived coercion and encourages dialogue (Porter, 1985).

Another method is about positioning SC as a Joint Learning Mechanism. When SC models are used to explore alternative materials, evaluate design simplification and assess volume and yield effects, they become joint problem-solving tools, not negotiation weapons.

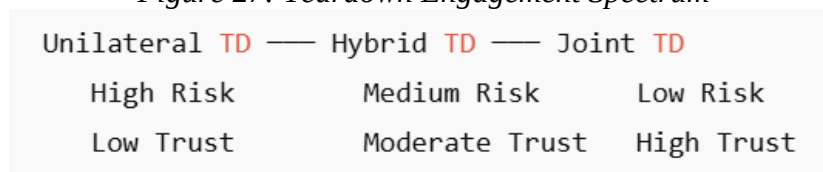
Table 11: Adversarial vs. Collaborative Use of Should Costing

Dimension	Adversarial SC	Collaborative SC
Purpose	Price reduction	Cost understanding
Output	Single-point cost	Cost ranges
Supplier role	Defended party	Knowledge partner
Trust impact	Negative	Positive

(Source: Zhang et al., 2021)

Let us now take a look at collaborative Teardown Models in the Networking Industry. The primary one is the Black-Box vs. Open-Box Teardown. Traditional teardown is often conducted unilaterally (“black-box teardown”). In contrast, open-box or guided teardown allows suppliers to validate assumptions, clarify process realities and protect IP-sensitive steps. This approach has proven particularly effective for optics and power electronics, where physical observation alone is insufficient to infer true cost drivers (Bengü, 2010).

Figure 27: Teardown Engagement Spectrum



(Source: Zhang et al., 2021)

Another collaborative strategy is selective teardown, focusing on non-differentiating components, packaging inefficiencies and over-specification. This protects supplier core IP while still yielding meaningful cost insights.

One of the strongest drivers of pushback is the immediate conversion of SC outputs into price demands. Effective organizations separate analytical learning phase and commercial

negotiation phase. This temporal separation preserves analytical integrity and reduces emotional escalation (Shank and Govindarajan, 1993).

Table 12: Confidence-Based Cost Communication

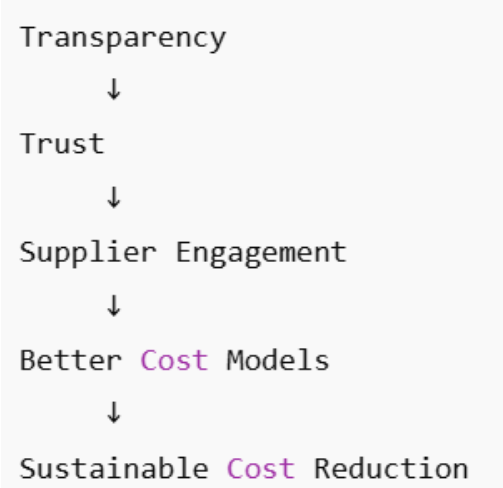
Confidence Level	Data Quality	Usage Guidance
High	Verified data	Strong negotiation input
Medium	Inferred data	Joint discussion
Low	Assumptive data	Hypothesis only

(Source: Zhang et al., 2021)

Also, it is important to use SC and TD as Organizational Enablers. Supplier-facing SC initiatives must align Procurement incentives, Engineering objectives and Supplier management policies. Misalignment, such as rewarding buyers solely on price reduction, undermines collaboration.

Collaboration improves when OEMs share demand forecasts, share design intent, share learning curves. Reciprocity signals fairness and builds long-term trust (Riley, 1987).

Figure 28: Collaborative Costing Flywheel



(Source: Zhang et al., 2021)

In below section, we will discuss about Incremental and Practical Solutions for the Networking Industry. Rather than radical transformation, incremental changes often yield the highest returns Introduce SC early in NPI rather than post-design, use teardown selectively for validation, not domination, focus on cost drivers under joint control and institutionalize “cost dialogue” workshops. These practices reduce pushback while preserving analytical value.

By repositioning SC and TD as collaborative learning mechanisms, organizations can increase frequency of application, improve data quality over time and strengthen supplier innovation partnerships, reduce long-term sourcing risk. This directly addresses the adoption barriers identified by Longauer et al. (2024).

4.8.2 Summary of Findings Based on Expert Interviews

This section integrates insights from semi-structured interviews of internal and external experts around procurement, design, component engineering, manufacturing, and commodity management. The interviewee viewpoints on how Should Costing and Tear Down impact supplier relationships, sources of resistance, and the circumstances in which these practices are considered to be collaborative rather than adversarial are considered.

1. Sources of Supplier Pushback Identified by Interviewees

Of all respondent groups, supplier opposition was named a common and predictable consequence of introducing Should Costing and Tear Down without sufficient context or alignment. Procurement and commodity management scholars acknowledged that suppliers viewed these methods as price pressure devices and not analytical techniques when cost models are put forward as fixed targets. Respondents in the design and component engineering fields reported that supplier pushback is magnified when teardown evidence is selectively applied and without regard to performance, reliability,

or complexity of integration. Manufacturers also reported that the suppliers were opposed to cost challenges that were perceived to be detached from process reality, yield risk, or capital investment needs. External experts identified that supplier opposition is often based on asymmetrical information and trust challenges, with suppliers frightened that a reduction in cost transparency will result in an erosion of margins without equal commitment from vendors or volume stability.

2. Reframing Should Costing and Tear Down as Collaborative Mechanisms

Interviewees repeatedly expressed that Should Costing and Tear Down should be framed as shared problem-solving tools for joint problem-solving, rather than unilateral negotiation levers. Procurement respondents report better supplier engagement when cost modeling is offered with a scenario context, leading to discussion not forcing conclusions. Design and engineering experts stressed the importance of teaching teardown experiences as learning artefacts by means of which to consider alternative structures, systems, integrations, and material designs collaboratively with suppliers. Manufacturing participants mentioned that partnership is enhanced when suppliers are allowed to communicate process decisions made during teardowns, therefore creating context around ostensible cost determinants. External interviews noted that companies with more experienced practices openly separate cost discovery from price negotiation, thereby decreasing resistance from suppliers.

3. Role of Cross-Functional Alignment in Supplier Engagement

One of the main reflections across the interviews was that effective collaboration with suppliers is built upon internal alignment before any outward involvement. Inconsistencies between design, manufacturing, and the procurement teams undermine credibility and lead to increased supplier scepticism, procurement respondents said. But technical descriptions and process knowledge were the most common way suppliers got

into a constructive conversation because challenges of cost are supported by sound technical descriptions — a key insight for design and manufacturing specialists who said suppliers are more open to constructive engagement. The participants from the commodity management group further emphasized why teardown cost insights should be presented as part of a coherent overall company view rather than a procurement initiative taking place at the discretion of individual managers. External experts have termed cross-functional alignment as a “prerequisite to moving supplier dialogues from price confrontation...to capability-based collaboration.”

4. Practices That Reduce Relationship Stiffening

Interviewees shared a number of practices that can help to ease relationship strain. Another common thread was selective transparency in which only relevant cost drivers were discussed to limit the inappropriate exposure of sensitive teardown information. According to procurement and commodity management respondents, collaboration is increased when the goal of teardown outputs is to explore common areas for cost-savings — for example, simplifying design, increasing yield, or automating production — instead of asking the team to offer immediate price concessions. Manufacturing consultants were quoted as keen on appreciating and retaining genuine supplier value, such as the quality of the system, capability to innovate, and the resilience of the supply system. External respondents noticed that such appreciation of value decreases the perception of Should Costing as a purely margin-driven approach.

5. Perceived Limits of Collaborative Application

While taking into consideration these practices as part of their supplier relationships, these managers did not all experience this but interviewed noted that not every supplier relationship could be changed in the way of a collaboration-based application of Should Costing and Tear Down. Procurement respondents reported that suppliers with very

differentiated IP, and even few competitors, are resistant no matter how to interact with them. Experts in design and engineering warned that overreliance on teardown learning could still be seen as intrusive, especially in high-tech sectors with fast innovation cycles. Manufacturers responded that cooperation is also restricted when cost pressures collide with capacity investments and long-term technology roadmap planning. External experts concluded that collaborative use is most appropriate in strategic or long-term supplier relationships, where mutual dependency and trust is already present.

4.8.3 Summary of Findings from Case Studies

Case Study: Power Supply Unit Teardown as a Tool for Supplier Collaboration

This case study examines the application of should costing and teardown analysis as a collaborative mechanism between a networking original equipment manufacturer (OEM) and its power supply unit (PSU) supplier. The focus is on addressing one of the most persistent challenges limiting the adoption of these techniques in industry: supplier resistance and relationship stiffening when teardown and should-cost models are perceived as adversarial tools.

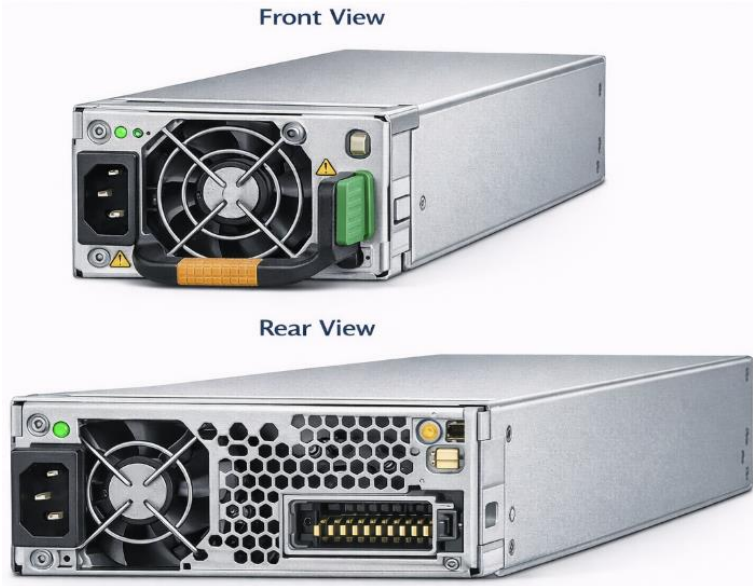
The PSU was selected because it is a high-value, high-volume component within networking equipment and is typically sourced from external suppliers under long-term framework agreements. Despite its apparent standardisation, the PSU integrates complex power electronics, thermal design, and manufacturing process decisions that strongly influence cost. These characteristics make it a suitable artefact for examining how teardown-derived cost transparency can either damage or enhance supplier collaboration, depending on how it is deployed.

Product Overview

The analysed product is a 750 W hot-swappable AC–DC PSU used in enterprise networking switches and routers. Externally, the unit conforms to industry-standard

mechanical and electrical interfaces, including fixed casing dimensions, airflow direction, connector layout, and handle geometry. From the procurement perspective, the PSU is often categorised as a “comparable” or “carry-over” design across suppliers.

Figure 29: External front and rear views of the 750 W networking Power Supply Unit (PSU)



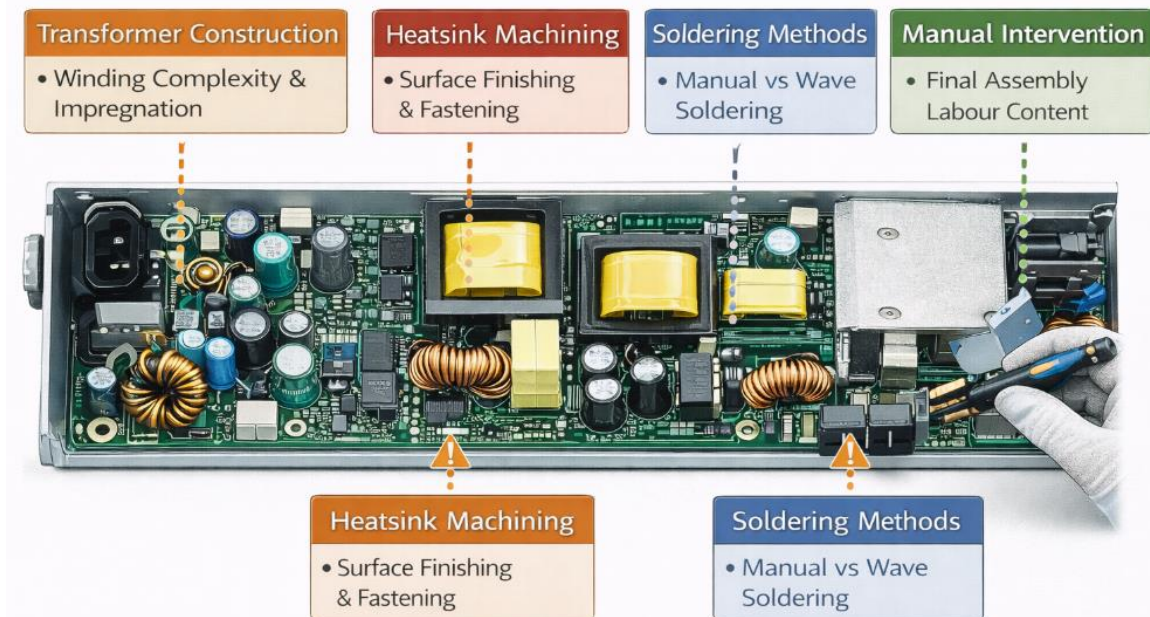
Teardown and Cost Transparency Process

A structured teardown was performed by the OEM's cost engineering team together with the supplier's manufacturing engineering functional group representatives. Teardown was consciously framed as an opportunity for joint learning instead of a cost challenge. It was this positioning that was key to developing supplier engagement. The teardown was performed with enclosure removal, EMI filter exposure, PFC stage, DC–DC conversion circuit, and thermal management components. Throughout their analysis, the choices of components, assembly complexity, automation and thermal system choices were all captured for each stage.

Identification of Cost Drivers Via Co-Teardown

The teardown revealed several high-level cost drivers that the OEM did not know beforehand. These covered the complexity of transformer winding complexity, heatsink machining and finishing processes, soldering methods and the extent of manual intervention in final assembly. Rather than using these insights to unilaterally claim that savings would go hand in hand with it, the OEM used them as conversations for action. For instance, the supplier proved that a costlier heatsink design could be driven by thermal margin issues that were based on the OEM's reliability standards which demanded a higher cost. That brought the discussion from "price challenge" to "specification-cost trade-off". An annotated internal architecture diagram (formed during TD and SC exercise on this PSU) of cost sensitive subsystems identified in the common teardown assessments, which was shown in below Figure.

Figure 30: Annotated PSU internal architecture highlighting key cost-driving subsystems.



Resistance from Supplier Pushback and Collaborative Engagement

Before this case, supplier resistance to should-cost, as discussed in this study, they were opposed to should-cost models for fear of intellectual property and oversimplistic misrepresentation of manufacturing complexities and oversimplified reality about the reality of manufacture. Such concerns are also echoed in other similar literature which has noticed that the teardown process can feel intrusive or accusatory (Longauer et al., 2024). In this study, resistance was diminished by separating process understanding from the negotiation process to be effective in a commercial context. The teardown outputs were presented as engineering evidence rather than pricing mandates. This differentiation proved crucial to preventing defensive responses

Research Question 7 Results

This case study shows that when costing and teardown analysis is redeployed from cost enforcement to process comprehension and collaborative tools, they can effectively be combined and utilized. The results showed that supplier pushback is less about the analytics technique and more about how its results are incorporated into suppliers' engagement. When assumptions were tested, specification-driven cost investigated, and together inefficiencies were identified by using teardown analysis, suppliers were more willing to disclose manufacturing insights. When similar analyses were employed only in the past to validate price reductions, relationships would decline. This case also demonstrates how incremental deployment — starting with only partial teardown and moving up to high-level cost drivers — makes perceived threats less of an issue, but yields actionable insights at the same time. This incremental approach tackles one of the principal impediments to broader adoption identified in the literature: the concern that teardown is only going to induce aggressive commercial pressures.

Implications for Networking Industry Costing Practice

The findings imply effective supplier collaboration rests on clear governance of technical cost understanding and commercial negotiations. Should costing and teardown outputs work best for underpinning design-for-cost discussions, specification optimisation and long-term cost roadmap alignment rather than immediate price challenges.

4.9 Conclusion

The latter provide final conclusions summarizing the findings and answers developed for the Research Questions. Conclusions will be presented in a question-by-question fashion as will each paragraph in the below.

RQ1 Conclusions: Networking hardware cost estimation takes a whole spectrum of tear down and should costing methods with unique benefits and trade-offs. The physical teardown provides empirical data, functional and reverse engineering provide deep insights, while bottom-up, parametric, hybrid, and automated models offer actionable cost estimates derived from these insights. The methodology chosen varies based on detailed nature needed, availability of data, limited resources, and question on cost. The best approach to find, interpret or optimise a cost in a complex network product is to mix methods backed with modern tooling. Thus, the findings indicate that should costing and tear down methodologies are practised in the networking industry, being a context dependent combination of methods, each with pros and cons. Although much of the value brought from Tear Down is in the development capacity and understanding of the marketplace, Should Costing is primarily appreciated through its focus on cost transparency and enabling internal and external decision-making, as well as providing supplier information. The quality of the data, the right fit in functionality and appropriate concern from an ethical and legal scope are nevertheless required if either approach to the

problem are to be successful. This case provides an example how comprehensive breakdown of a pluggable optical transceiver module can have a large positive effect on competitive cost modeling and should costing within the networking industry. Teardown insights are an input to the software application for engineers, designers, and procurement professionals, but successful integration into parametric models and firm-level alignment are required. However, the above two methods have their shortcomings in which practitioners need to manage in practice, most notably the accuracy of the data, investments on resources, and legal obstacles; despite the fact that they offer the most advantages, where integrated with cross-functional capabilities.

RQ2 Conclusion: When employed consistently, teardown analysis serves as the engine for cost driver discovery instead of a benchmarking mechanism. Incorporation of physical dismantling, manufacturing inference, functional decomposition and architectural dependency modelling, teardown allows us to identify and quantify first-, second- and third-order cost drivers in networking products. This formalized approach overcomes the drawbacks of conventional teardown and enables more accurate, repeatable, and decision-oriented should-cost models. Overall, the findings indicate that, if structured and executed as part of a structured inter-disciplinary approach, teardown analysis systematized can be applied to systematically identify as well as measure some of the critical cost drivers in networking products. Teardown provides a critical understanding on architectural and physical cost sources that help achieve more effective supplier interaction and Should Cost analysis. Resource needs, litigation, and access to non-physical cost element restrict its effectiveness but otherwise, the cost-reduction process. This demonstrates that teardown analysis is more effective when integrated as an enabling component in the overall cost analysis than as an intrinsic quantifying method. The case study also illustrates that the systematic dissection analysis, performed with

uniform disassembly process and extensive component identification, can result in successful results. For instance, in a networking product such as a QSFP optical transceiver in a subassembly-to-cost-driver mapping enables the identification of components and the processes that deliver the primary cost drivers. High silicon/photonics costs, PCB complexity, and calibration effort are some of the patterns that illustrate and serve as inputs to should cost models quantitatively. Such a qualitative method directly addresses your research question in a real networking product and provides a structured method for the use of teardown to facilitate identification, as well as quantification, of cost drivers for that product.

RQ3 Conclusion: In conclusion, this study proves that the successful implementation of Should Costing and Teardown in networking enterprise not requires a new set of tools being developed – but rather a mix and matched approach using specific, integrated ones. Parametric modeling, TDABC, learning and yield models, structured and inference-based teardown, DSM-driven architectural analysis and transaction-cost-aware costing combine to offer incremental and meaningful remedies to long held barriers not to wider usability. These tools link analytical rigor to industrial applicability so Should Costing and Teardown can be regarded as strategic decision-support tools as opposed to one-to-one cost-savings. Overall, these results suggest that modular, hybrid, and integrative tools and methods, as opposed to singular or static, are more appropriate to the Should Costing and Tear Down in network sector. Crossfunctional teamwork, the use of hybrid cost models, parametric tools, structured teardown frameworks, and knowledge repositories coalesce into a single, and incremental solution. These strategies collectively confront key challenges of data uncertainty, scalability, and organization fit, but do not eliminate everything that limits.

RQ4 Conclusion: High upfront cost, diminishing returns, and organizational capabilities barriers are structural obstacles for traditional Should Costing and Teardown approaches identified by this research. But these challenges can be mitigated by such means as incremental approaches to analysis, reusable cost libraries, architecture-centric learning, distributed capability development approaches and governance methods. As opposed to going for exhaustive cost transparency, many organizations within the networking industry today can create deeper value through learning, adaptability, and decision significance. In this way, should costing and tear down can shift from being expensive analytically run drills to embedded capabilities at the heart of strategy to help become competitive. The findings seem to converge into some sort of a consensus that the high upfront expense and decreasing returns of Should Costing and Tear Down might be mitigated through a transition away from an exhaustive, unitary analysis into a selective, incremental, and capability-based practice. Several interviewees reported that better reusing the historical findings, embracing parametric and virtual methods, and building cross functional competence will increase the effectiveness and frequency of the use. Structural barriers were most attenuated and addressed through shared ownership, specific skills development, and integrating cost analysis in established activities as opposed to rolling out new tools completely. In this way, RQ4 specific costs can be mitigated and in turn, high upfront costs can be minimized by implementing modular and partial approaches to teardown. Reduces diminishing returns and can be reduced by restoring teardown artefacts by using only architectural changes. Most of the benefits come in incremental solutions — proxy-based cost drivers and visual teardown libraries, for instance — for less of the cost. The barriers to organisational capability can be tackled by standardising the outputs of the teardown and integrating them into conventional engineering and sourcing actions. The lesson here is the problem is not the absence of

should-costing and teardown theory but the mismatch between the traditional approaches and the realities of the industry. If organisations take these incremental, modular, and knowledge-based approaches — as the optical transceiver teardown illustrates — they will continue to benefit from should costing and teardown without incurring prohibitive costs or effort.

RQ5 Conclusion: This research shows that Reverse Referencing Risk is an inherent flaw, not a accidental mistake, in Should Costing and Teardown analysis, but rather a structural issue of Should Costing and Teardown analysis in the networking industry. Product similarity can sometimes substantiate process reuse assumptions but these must be tempered towards specific criteria regarding technology maturity, supplier continuity, volume, and tolerance stability. This risk may be systematically managed using incremental, practical methods including process signature mapping, multi-order cost driver analysis, dependency validation with DSM, confidence-banded costing and mechanisms to govern RRR. These techniques do not require full supplier transparency or undue capital expenditure, but greatly strengthen the robustness and integrity of SC and TD outputs. Ultimately it would be better to transition RRR shifts Should Costing and Teardown from pattern matching to disciplined inference systems which in the end, is best suited for the complexity and dynamism of modern networking hardware. As seen from the PSU case study Reverse Referencing Risk is highly visible in power electronics used in networking products. Even though some scenarios allow for reuse of should-cost models, many commonly taken equivalences are not applicable under teardown examination. The results underscore the importance of data-supported validation and demonstrate that partial teardown can represent an efficient mechanism by which to protect against erroneous process assumptions at a lower cost than full teardown. By basing reverse referencing decisions on physical and architectural evidence, organisations

can reduce estimated cost and avoid the expensive and unwieldy overhead that historically accompanies teardown analysis. These findings are a specific empirical contribution to understanding the management of RRR in industrial should-costing practice.

RQ6 Conclusion: This study argues that legal, ethical and IP issues are more than incidental limitations to should-costing and teardown, rather they are core design specifications that dictate how these methods can be successfully implemented in practice. The risk of teardown extends beyond legal requirements in the network sector where products are a deeply knowledge base – from technological and supplier – and it also includes trust, reputation and the access to innovation. By clearly distinguishing between cost inference and design replication, integrating legal and ethical controls, and employing range-based, confidence-aware outputs, organizations are able to implement SC and TD legally defensible, ethically responsible, and strategically sustainable methods. Ultimately, addressing these concerns responsibly would enhance, not undermine, the credibility and sustainability of Should Costing and Teardown as decision-support instruments. As a whole, the results suggest that legal, ethical, and IP considerations are part of How Should Costing and Tear Down is performed in networking. Respondents overwhelmingly thought these considerations influenced the scope, design, approaches, and communication of cost analysis activities and not as sideline issues as they were perceived to be in the other. Although Should Costing and Tear Down are acknowledged to be highly informative tools, its use is tempered by the pressure to balance cost transparency, compliance, legality, ethicality, and intellectual property rights. The results indicate that organisations increasingly view such concerns not as post hoc checks, but instead, as structurally defining aspects of their cost analysis practices.

RQ7 Conclusions: This study shows that the pushback from suppliers is not a natural by-product of Should Costing and Teardown, but a response to how these techniques were developed, governed, and used. In the context of the networking industry, where vendor expertise is integral to the success of each product in terms of its performance and manufacturability, adversarial SC and TD strategies are counter-strategic. When recontextualised as instruments for shared cost analysis, backed by ethical governance, trust-based outputs and reciprocal visibility, SC and TD can become platforms for symbiosis rather than rivalry. This evolution is important for future sustainable competitive costs, but without loss of trust, innovation or resiliency from suppliers over time. Taken together, our results suggest that Should Costing and Tear Down can be used to facilitate supplier collaboration when integrated within a larger relational and organisational setting. Interviewees repeatedly expressed that resistance from suppliers isn't as much a matter of the tools as it is the way the tools are presented, construed and administered. Collaborative outcomes were correlated with transparent intentions, cross-functional alignment, selective disclosure and the acknowledgment of the value of the supplier. When they were utilized primarily as negotiation tactics, however, these methods were also more likely to lead to relationship deterioration, echoing concerns in the available literature regarding obstacles to broader adoption. This PSU case study offers evidence that costs and teardown analysis should not by default impair supplier relationships. Relationship outcomes rely, rather, on intent, framing and governance. When used as a joint analytical platform such techniques can enhance trust, increase cost transparency and contribute to co-creation of value. These results respond to Research Question 7 and are also relevant to considering how costing can be translated from confrontational tool into collaborative tool within the networking industry.

CHAPTER V: DISCUSSION

5.1 Discussion of Results

Chapter 3 reports several findings of the research about changing application of Should Costing and Tear Down Analysis in the Communication Networking Product Industry. The conversation interprets empirical findings based on the industry interviews, case reviews and comparison into the existing literature. The findings are discussed in relation to the aims, addressing how these methods are moving from competitive, adversarial cost control practices to collaborative, value-centered practices that can strengthen supplier relationships, drive innovation, and establish transparency on life cycle costs.

5.2 Discussion of Results on Research Question One

RQ1: What techniques/methods currently in Networking Industry are feasible for use in Should Costing and Tear Down costing? What are their pros and drawbacks?

The goal of this study was to analyse the various methods of Should Costing and Tear Down that are currently applicable in networking and to critically analyse their strengths and weaknesses. From the reviewed literature, expert-notes, and the optical transceiver case study, the findings suggest neither Should Costing nor Tear Down is a single standard process in current times. Both are not fixed, but flexible analytical approaches that are amalgamated, modified and limited by complexity of products, capability of organisation, availability of data and/or legal constraints. The discussion that follows interprets these findings by situating individual techniques within the general industrial context to which they belong, namely networking hardware. This environment is characterized by a rapid technological evolution, high-value components and fragmented supply chains. Instead of finding a "best" method, the result suggests that effectiveness is in large part determined by how well some technique fits within the decision context where it's put to use Tear Down Techniques in The Networking Industry. The results

validate that physical tear down is still a ubiquitous method for the calculation of the cost of Networking products, such as optical transceivers, line cards and power modules that exhibit high mechanical integration and component density. Traditional physical tear down has a solid material content, component selection, assembly methods, the latter being often overlooked by supplier bills of materials.

The comment made from literature and interviews reveals that this method is especially well-received for its tangibility and credibility, grounding cost decisions in observable evidence, not in abstract judgments. Yet the output also shows that the analytical value of common physical tear down is inherently limited. However, it does not account for the considerable non-physical components to total product cost, including embedded software development, calibration know-how, testing algorithms and supplier-specific intellectual property, even though it performs particularly well in uncovering physical cost drivers. This limitation was reinforced by participants in interviews, who warned against treating tear down outputs as full cost estimates instead of snapshots of the total cost structure. The argument therefore supports this argument: Physical tear down is necessary but insufficient to work for all advanced networking products.

Results:

Functional and logical tear down methods are identified as an important supplement to purely physical approaches. These methods help map functional subsystems, interfaces, and dependencies, allowing analysts to match cost drivers as they impact architecture decisions instead of as isolated components. The transition from components-centric analysis to more architecture-aware analysis is important in modular networking systems given they have low cost and cost behaviour resulting from integration options, standard compliance requirements and performance requirements. On the one hand, the idea of functional tear down increases explanatory power, yet also heightens the initial level of

entry required from a range of actors—from the design leader or business executive—in a particular domain to a core industry.

Reverse-engineering enriched tear down techniques take this a step further revealing internal silicon structure, packaging technologies and manufacturing process indicators within internal network architectures. The outcomes suggest that these techniques provide better accuracy in process inference and cost driver identification, especially for custom ASICs and high speed optical engines. However, the literature review clearly explains that these gains have some serious financial, organisational, and ethical implications. Expensive capital, expertise, and increased legal and intellectual property risks limited the normalisation of these methods and many institutions will move towards conservative scopes or non-invasive models. So, reverse engineering is a capability that cannot be thought of widely, as an industry practice. The discussion of tear down techniques reveals general tradeoffs to be found among depth of analytical capabilities and pragmatic feasibility. However, as the tear down method continues to develop, due to resource demands, there is a need for method choice matching specific analytical goals and thus the scope of their applicability limited. Should Costing Methods and Models. The findings suggest that Should Costing within the networking industry is hardly ever realised as an integrated cost control model.

Bottom-up or clean-sheet costs are generally perceived to be the most transparent and the most analytically rigorous methods, especially when used to fight pricing from suppliers or support the make-versus-buy decision. The discussion also affirms the desirability of these models for connecting cost results to engineering and process assumptions, in order to aid fact-based negotiation and internal decision making. The results also show that applications of bottom-up models are very strongly constrained by availability of data and organisational effort. Inherent high-resolution inputs (cycle times, yield data and

overhead structures) are usually unavailable without vendor agreement, leading to uncertainty and subjective judgment in what may be considered objective models. Thus, the discussion supports interviewees when they expressed that clean-sheet models, though conceptually sound, can lose credibility if they cannot be transparently verified with their assumptions. Parametric cost estimation models also become an alternative response to these problems.

Speed and scalability are their great advantages and make them particularly suited at the early stages of their design and portfolio analysis. The discussion illustrates how parametric models fit closely with the iterative nature of business development for networking products. Early architectural choices thus bear disproportionate cost burdens on what we do next. However, their dependence on historical data makes them less accurate in response to rapid technological change, which is a characteristic feature of the networking industry. It therefore follows that parametric models are most effective when used directionally rather than deterministically. Hybrid cost models using teardown results, parametric relationships and expert judgment emerge in the findings as the predominant industrial model. The analysis views this prevalence as an adaptation to the inherent limitations of alternative techniques in a pragmatic context.

Hybrid models combine methods effectively, allowing organizations to optimize analytical depth and feasibility, which is suited for product maturity and data quality. Nevertheless, the discussion also admits that hybridisation makes its own challenges, in particular in terms of consistency and avoiding the danger of compound mistakes across integrated assumptions. Automated and AI-augmented costing tools represent a major advance in practice. The results imply that these devices provide large gains in efficiency and decrease manual work, and create uniformity of part recognitions and data extraction. From a conversation standpoint, these technologies seem to hold promise in overcoming

scalability challenges, yet still relying on proper training data and a considerable up-front cost. So they are today preferred by bigger firms with more advanced cost engineering capabilities. Target costing, although not a costing tool itself, is considered as an important contextual framework guiding the interpretation and use of Should Costing measures and outputs.

The results highlight that target costing provides a coherent approach in which technical cost estimation works in harmony with market conditions and strategic goals. But the conversation is clear: its effectiveness hinges on an alignment with what the organisation does — and that, interviewees claimed, is a recurring challenge when the work is multi-disciplinary. Benefits, drawbacks, and cross-functional implications. Between Should Costing and Tear Down techniques, a consistent discussion about trade-off is evident. High transparency and accuracy techniques are resource intensive and hard to scale whereas speed and flexibility based techniques give up granularity and precision. Crucially, the findings indicate that most of these perceived disadvantages are not inherent to methods/techniques but are a poor match between method capability vs application context. Another important interpretive insight from the interviews is that organisational perception can often determine the performance of these techniques. When Should Costing is cast as a negotiation weapon rather than something to be used for negotiations only, a lot of the times it can likely be met with resistance and scepticism. When framed as a collective analytical methodology used in the context of design optimization and process improvement, on the other hand, it is more likely to be accepted and its impact also rise. Tear Down approaches follow a similar pattern and tend to gain in value when embedded within cross functional review processes rather than as isolated analytical exercises. The discussion also emphasises longstanding limitations which present challenges for current methods, which are often not effectively addressed.

The non-physical cost drivers, especially software, firmware, validation and proprietary know-how, remain difficult to accurately quantify.

Legal and ethical restrictions also constrain the depth and pattern of tear-down that is performed and caution in the interpretation of the results and the degree of use of this advanced technique is required. Conclusions and Practice Implications. Conclusions and implications In aggregate, the discussion reveals that modern network outsourcing practices with Should Costing and Tear Down are patterning not consistent with standardisation but pluralism in the methodologies applied. In this context, the benefits of current paradigms to cost transparency are, to provide the basis for informed decisions and to facilitate competitive learning. They are thus limited by data opacity, business restrictions and the increasing visibility of intangible value drivers. The results therefore indicate that whether Should Costing and Tear Down will prove to be most beneficial is not simply a function of methodological sophistication but whether they integrate purposefully, be contextually sensitive, and involve cross-functional efforts. This interpretation confirms that as a view, all of these methods must be considered development of management capability, not static tools of analysis, but evolved as much as an outcome of organizational maturity as of organisational design.

5.3 Discussion of Results on Research Question Two

RQ2: In what ways can teardown analysis be used in a systematic way to identify and quantify costs of key drivers of networking products?

This study aimed to investigate how teardown analysis can be systematically employed to determine and measure important cost drivers for networking products. These results of the literature review, expert interviews and optical transceiver case study all show that the use of teardown analysis in an organized and theory-informed approach yields a strong empirical evidence base for the identification of potential cost factors hidden by supplier

price opacity, architectural complexity and rapid technological change. One of the main points that is presented in the findings is that teardown analysis appears to work best not as a discrete costing method, but as a mediating tool that connects the physical products' value chain to the theory of costing driver. Historical averages and supplier quotes are prevalent forms of cost estimation in networking hardware which typically collapse heterogeneous cost drivers into aggregated price signals. These findings demonstrate that teardown analysis is the solution to this limitation, which reestablishes a direct link between product architecture, manufacturing processes and cost behaviour. This comes with a special importance for networking products, since more of the cost is associated with second- and third-order drivers (e.g. yield loss, test complexity, learning effects, and architectural coupling), rather than raw material content alone.

This literature driven methodology demonstrates that systematic teardown analysis needs to move from 'just disassemble ad hoc' analysis into progression of analysis in stages. Discussion of outcome shows that early stage product selection and scope definition is crucial for the analytical relevance and reproducibility of the data. With no boundary for teardown, teardown work becomes erratic and it has limited the potential to compare products within a product family or with respect to generations. This finding echoes previous research highlighting the importance of methodological discipline in the determination of cost analysis credibility over analytical depth by itself. The physical teardown/bill-of-material reconstruction stages were essential for identifying first-order cost drivers — component count, material selection and packaging technologies. Nonetheless, the conversation emphasises that these first order cost drivers explain only a portion of the cost behaviour in the context of networking products. For both interview evidence and case study observations evidence physical visibility is inadequate to explain the disproportionate cost concentrations detected in subsystems

(e.g., optical engines or high-speed data paths). This suggests that teardown analysis needs a second stage of manufacturing process inference to address second order drivers regarding assembly complexity, tolerances, and yield sensitivity. Our results suggest that manufacturing process inference is a defining step in systematic teardown analysis. By reading physical design cues—including PCB trace density, via structures, optical alignment features, and fastening methods—analysts can deduce likely manufacturing routes and process constraints. The discussion of this inferential step shows that teardown analysis transitions from descriptive inspection to explanatory cost modelling. Notably, there is a sense for professionals, not as an exercise in precision, but as a method of minimising uncertainty and narrowing feasible cost frames, as established through expert interviews. This suggests that teardown's value is not really to provide precise cost figures but rather to pinpoint the process assumptions which will have major implications for the overall cost of a process.

Further enhancement of the systematic identification of cost drivers from functional and architectural decomposition can be done using Design Structure Matrix (DSM) techniques that expose interdependencies not visible within the component-level analysis. DSM-based interpretation allows cost drivers to be understood in relation to architectural coupling instead of as isolated pieces. As with large networking products, where a change in a single functional block can propagate throughout power, thermal and signal integrity fields, this architectural view is necessary to understand why design choices that are perceived as small in size result in outsized cost effects. These findings emphasize the continued importance of architectural cost theory in current networking hardware scenarios. The recognition of material, process, and system-level cost driver factors demonstrates the suitability of extended cost driver theory to networking products. It is clear that teardown analysis allows analysts to go beyond first-order metrics, and

systematically surface higher-order drivers (e.g., supplier maturity, platform reuse strategies, and volume–risk asymmetry). Interviewees continuously emphasized these drivers as key to their procurement negotiations and internal decision-making processes which could be challenging to substantiate without empirical support. Teardown analysis brings that anchor home by connecting abstract cost drivers to concrete design and manufacturing information.

The results of quantification of cost drivers emerge from a hybrid methodology rather than merely the bottom-up computing. Teardown analysis supports quantification more by proxy measures and parametric relationships than direct calculation of costs, the discussion suggests. Some of these may be quantitative metrics (PCB layer count, component density, optical alignment steps, test coverage etc.) that act as scalable proxies that can be directly converted to cost impacts using known models (e.g., learning curves or time-driven activity-based costing). This approach tackles a fundamental practical limitation, as noted in the interviews: access to detailed supplier cost data. Relative weighting and sensitivity analysis of costs (or other tools based on a value chain), allow teardown-based quantification to improve decision usefulness while allowing for non-trivial levels of transparency of data. It was found that validation and sensitivity analysis play a fundamental role in keeping confidence in teardown cost insights. The discussion emphasizes that without matching suppliers' quotes, historical data, and expert judgments teardown-based decisions risk being reduced to speculation. Interview results emphasise that validation cannot be just a technical exercise but an organisational one too, with cross-functional communication necessary to distinguish between avoidable cost and ones that depend on reliability, compliance or long-term performance. This supports the notion that structured teardown analysis most effectively serves as a joint analytical mechanism, not as procurement only function. The optical transceiver case study

illustrates how teardown analysis can be put a concrete example into practice to both pinpoint and comparatively quantify key cost drivers in a real networked item as well as the ways in which that information is obtained and used. The case study demonstrates the validity of a hierarchical teardown-to-cost-driver mapping described in the literature from a physical observation through to process implication and finally to cost driver categorisation. As its high-value silicon, photonic components, and assembly/test complexity are dominant in the case study, the results align closely with industry benchmark data, giving external plausibility to the teardown-derived insights. Simultaneously, the case also demonstrates the limitations of teardown analysis, namely in terms of the non-physical cost components like firmware implementation and proprietary algorithms requiring supplementary analysis approaches. In conclusion, the results-based discussion suggests that teardown analysis when employed in a systematic way is a great tool to determine and shape important cost drivers of networking products, and allows for partial measurement by proxy-based and parametric methods. The main contribution of this approach is to convert tacit assumptions about costs into observable cost drivers that can be debated, validated, and improved in various functions. Rather than deprecating the traditional costing models, systematic teardown analysis strengthens them by anchoring cost models to empirical products and processes. This makes teardown analysis a core feature of modern should-cost practice across challenging technology-rich types of industries like networking hardware.

5.4 Discussion of Results on Research Question Three

RQ3: Which tools and methods are best suited to Should Costing and Tear Down for products in Networking Industry, providing incremental approach to some contemporary Challenges in Should Costing and Tear Down?

The findings of the research, which look at the best tools and methods appropriate to organizations in the networking industry for Should Costing (SC) and Tear Down (TD) and how these tools are able to show a little workable improvement to persistent application solutions, are discussed in this section. This discussion is informed by the literature review, expert interviews and by the optical transceiver case study, and seeks not only to understand what tools will be used in this industrial context but also why there are perceptions of those tools as appropriate. An important result of the findings is that the selective, infrequent implementation of SC and TD in the networking industry is not necessarily based on methodological immaturity aspects but rather, because they do not fit well with the structure of networking products. A high cost concentration in a small number of components, a rapid technology cycle, and architectural modularity as well as suppliers' lack of visibility undermine the utility of single-method approach. This observation is consistent with previous criticisms of static cost models, predicated on stable processes and transparent data environments that are hardly present in the manufacturing of high-tech electronics (Cooper and Kaplan, 1988; Sandborn and colleagues, 2010).

The discussion of method appropriateness criterion accentuates that in the networking context suitability is less a matter of theoretical completeness and more a pragmatic need under uncertainty. The reliance on partial cost visibility in the literature and interviewees echoes an industry reality where detailed supplier process data is seldom available. Since we can rely on tools that cannot work with all of our data, methods, for instance, parametric and feature-based models, are the most useful. These tools support cost reasoning and architectural trade-off analysis early in the design life cycle and serve to inform design decisions early enough before cost lock-in begins. But they also show that their use is limited for use cases with new technologies and process changes (it is thus

still fair to assume that parametric methods are employed as directional not definitive tools). The results describe Time-Driven Activity-Based Costing (TDABC) as a method to complement traditional material-led costing, as it enhances the analysis of test, validation and reliability costs for visibility. It is particularly pertinent in networking products, as testing and qualification are essential to product acceptance – this shows. That TDABC helps reveal “hidden” costs is supported by interviewees’ findings, suggesting that cost insight improvements can be made incrementally and without full depth of integration. Still, because of the dependence on accurate time estimates and capacity rates, the efficacy of TDABC may be reliant on stage-related dimensions of organizational maturity and procedure discipline, which may explain its inconsistent uptake. Addition of learning curve and yield-based approaches overcomes a further shortcoming of traditional should-costing approaches, being that they ignore the change in cost behaviour.

The results showed that frequently networking products have rapid capacity ramp and short market window periods, and dynamic cost simulation is critical. The conversation described here affirms Wright (1936) and Argote and Epple (1990) that cost evolution is a function of accumulated experience rather than static design elements. Instead of precision, model learning adds incremental realism to this data, helping decision-makers explore cost trajectories instead of point estimates. It appears to be quite significant if we consider transaction-cost-informed approaches in extension of should costing. In doing so, these approaches acknowledge that cost cannot simply be attributed to production efficiency and include supplier dependency, contractual rigidity and switching risk. These interview data suggest that such a wide framing assists in better sourcing and make-or-buy choices in a world where suppliers are clustered with capabilities to the detriment of one another. This is consistent with Williamson’s (1985) argument that economic

decision-making is inseparable from governance infrastructures, and therefore accounts for how narrowly defined cost models may not affect corporate strategic decisions within the networking industry. As for methods of teardown, the findings point to a movement from ad hoc physical disassembly towards systematic and analytic discipline. Although there was widespread criticism that the teardown that occurs was analyst dependent, structured physical teardown frameworks were consistently stated to enhance repeatability and credibility. We find that standardisation is a methodological improvement, but it is also an organisational enabler for the benefit of the operation, in that the teardown data can be reused in any programme and be shared across different functions.

Process-inference-based methods to perform teardown were the most apparent in areas of limited access to manufacturing-controlled-data. Reliance on visible features such as PCB stack-ups, connector technology and thermal solutions indicates a practical response to supplier opacity. Whilst these approaches can't eliminate uncertainty, they provide the appropriate information to discern leading cost drivers that can inform decisions and not require proprietary information to be withheld. The application of architecture informed teardown techniques, in particular those that use DSM methods, is one of the most notable incremental contributions to the results. DSM-based analysis overcomes a central limitation of component-centric teardown approaches by accounting for interdependency between components and subsystems. Notably, in modular networking platforms, cost behaviour is primarily influenced by architectural coupling, rather than cost per individual part. This evidence builds upon work (Hernandez et al., 2025) by illustrating the practical application of architectural thinking in cost analysis. A recurring theme observed in the literature and interviews is that no single tool or process can handle the complexity of networking product cost structures. The advent of an integrated toolchain

approach indicates an industry preference to mix complementary techniques that will address a limitation of each model. The discussion suggests it is an integration that makes it possible for organizations to balance accuracy, effort, and compliance in generating cost insights that actually deliver a decision rather than a very analytical output. The expert interviews underline the role of cross-functional integration as an enabling mechanism rather than a mere adjunct consideration. The insight that tools generate legitimacy in connection with understanding shared across engineering, procurement, and manufacturing practices explains how visual or architectural approaches are especially effective. This is in line with work on the role of cost models in decision-making, which indicated that cost models affect decisions most strongly where they stimulate dialogue, rather than imposing results (Cooper and Kaplan, 1991).

The optical transceiver case also offers empirical evidence as to how systematic teardown in conjunction with should-costing tools results in the ability to isolate target cost drivers and establish relative metrics. Based on its conclusions, the results from the case study indicate that the value of teardown is not an objective estimate of cost, but an insight into core cost drivers that cannot be identified with traditional supplier pricing methods. This integration between physical disassembly and parametric (or process-based) models is illustrative of incremental insights even driven by confidential pricing and IP constraints. These advancements, however, also reveal a lot of caveats. Non-physical cost drivers like firmware development, system validation and intellectual property, however, remain hard to quantify using the tools currently available. Moreover, the maintenance of good models and depletion of knowledge bases still limit scalability. These results imply that while adequate tools and methods can alleviate plenty of hurdles, they do not negate the need for organisational judgment and governance. To sum up, the conversation suggests that the most suitable tools and manner should costings and tear downs in the context of

networking industry should be the ones who can face uncertainty, employ architectural expertise, and focus above all else on integration. Progressive ideas arise not only from new processes, but from an evolutionary collection of the state-of-the-art tools we have, applied to the structural conditions of the networking products. This interpretation also clearly indicates how SC and TD—if adapted judiciously—can still have meaning and validity even in the face of ongoing challenges and directly responds to the research question.

5.5 Discussion of Results on Research Question Four

RQ4: What can be done about the high upfront costs and diminishing returns of Should Costing and Tear Down? Are there any incremental solutions on the table here? What do we do as organizations to mitigate the Organization Capability Barriers that hinder the regular use of Should Costing and Tear Down?

Based on the literature review, experts' interviews, and a case study, it is concluded that a poor application of Should Costing (SC) and Teardown (TD) in the networking market is not caused by any methodological issue but rather results from mismatch between traditional analytical methodologies and real industrial practice. Although SC and TD are considered well accepted decision-support tools in theory, the utility of SC and TD is limited due to high initial investment, diminishing marginal learning after practice and organisational capability limitations. The subsequent discussion interprets these findings in the context and process of demonstrating how (indirect) incremental adaptations, rather than radical reformation of methodology and methodological approaches, may enhance (at least in terms of sustainability) the tangible benefits of SSPs.

Interpreting High Upfront Cost as a Formal, Not Casual, Block Onset

Across all data sources, high upfront cost is a structurally embedded feature of traditional SC and TD practices. This cost is characterised in the literature as being mostly fixed, the consequence of specialized knowledge and cross functional coordination and inordinate amount of labour necessary before any useful insight can be generated. Our findings from conversations, and interviewees' responses, confirm this interpretation, with procurement and commodity managers citing the labour expended in reconciling incomplete cost data, and engineers emphasizing reliance on specialist knowledge from design, manufacturing and test services. The case study of the QSFP transceiver also reinforces this structural understanding. Even for a small and commercially mature product, the teardown demanded careful handling, documentation, and expert interpretation which showed that upfront effort is inevitable when SC and TD are implemented as they should be, in broad, comprehensive form. Significantly, though, the case study also suggests that the scale of this upfront investment is fundamentally determined by analytical scope and intention. This proves that the high cost is not an intrinsic limitation of SC and TD as such, but a result of the rigorous and uniform application of these approaches despite their criticality of decision.

Cheaper Methods of Reduction in Costs as a Reframing of Analytical Ambitions. The hierarchical approach that was mentioned in both the literature and professional interviews could be seen to be an idea to re-orient the analytical ambition, and not a simplification in methodology. Rather than representing SC and TD as all-or-nothing activities, practice increasingly moves to distinguish between exploratory, confirmatory and strategic applications. This corresponds to interviewee reports of an increasing trend in selective deep dives with respect to cost dominated sub-markets, supplemented by parametric or benchmarking analysis at a higher level. This line of reasoning is also supported by the case study evidence showing that micro-level teardown produces a

significantly higher percentage of useful information for at a fraction of the cost of full product disassembly. Organisation can vastly decrease repetition by establishing baseline cost drivers for stable modules and returning to their most recent state across product cycles allowing them to retain analytical relevance. This finding aligns with the literature's focus on modularity and reuse, implying incremental approaches are not simply practical compromise; these methods are also theoretically inline with product architecture principles.

Learning Saturation: Why are we seeing diminishing returns? While diminishing returns for repeated teardown exercises are reported in literature, interviews and case studies alike, this relationship reveals nuance, not simple analytical fatigue. From design, manufacturing to engineering functions interviewees associate that diminishing returns is often due to further analysis of products that utilize similar architectures. After identification of cost drivers at component level, additional physical teardown adds little new, particularly in places where we increasingly know where value is placed in embedded software, firmware, or proprietary processes. The results indicate that the diminishing returns are because learning has not stopped, but learning is captured at an inappropriate level of abstraction. Use of an architectural-focused model, such as DSM-centred analysis, reorients teardown learning from component enumeration to dependency analysis. The case study indicates, too, that architectural relationships and module interactions yield insight even for high component familiarity (e.g., high familiarity with elements of building blocks and their structural context). In this way, diminishing returns are lessened, not by ramping up analysis-heavy tasks, but by redirecting attention to learning. From Static Cost Analysis to Longitudinal Cost Learning. Another interpretive point focuses on the temporality of cost data. Conventional SC and TD methods treat one analysis as the ultimate snapshot, which

results in perceptions of decreasing value through time. Contrastingly, interviewees and external experts focus on the importance of longitudinal cost driver tracking, with the teardowns being correlated throughout technology nodes, supplier maturity stages, and volume ramps. This perspective is supported in the case study, which identifies how proxy-based measurements extracted through teardown observations, e.g. PCB complexity or optical alignment effort, can be used again to monitor the evolution of cost without the need to base a series of multiple estimation results. This indicates that the use of SC and TD become more meaningful when outputs are observed as developing organisational knowledge, rather than viewed as analytical artefacts in isolation. This reading of the learning curves correlates with the theory of learning curves and further supports the explanation that diminishing returns are not a problem of the methods themselves, but rather have something to do with how learning is stored and reused. The primary constraint of frequent use is the organisational ability.

Although technical and economic barriers exist, the debate suggests that organisational capability barriers ultimately present the most significant impediment to high frequency use of SC and TD. Interview results strongly demonstrate that fragmented ownership, unequal distribution of skills and lack of cross-functional engagement are major barriers. This perception of SC and TD as procurement-driven negotiation tools compounds their resistance from engineering and manufacturing teams, reducing their adoption and credibility. According to the discussion points, these barriers are aggravated by SC and TD being treated as specialist activities instead of embedded organisational practices. The case study and interview evidence both suggest that sharing capabilities across roles—rather than a singular skill set in a small group—allows you to scale and scale more sustainably. Visual and explainable cost models and structured teardown templates provide a powerful tool towards facilitating this spread of capability, in turn

decreasing reliance on single professionals and facilitating knowledge transfer.

Integrating SC and TD into Current Procedures to Minimize Resistance. Another significant interpretative result of the case study is the evidence that embedding teardown outputs within the organisational processes—e.g. design reviews, sourcing decisions, supplier discussions—has proven to be beneficial. This connection also reduces the perception of SC and TD as extra overhead to the existing system and instead makes them the tools that enable such decisions. Interviewees also indicated that embedding helps acceptance as well as internal friction by shaping cost insights as learning rather than enforcement tools. This result indicates that breaking down organisational barriers does not necessarily involve significant changes but rather careful alignment of SC and TD outputs to existing workflows and governance.

From an academic lens, this reinforces the necessity of socio-technical alignment, whereby methodological effectiveness hinges as much on organisational context as on analytical rigor. *Synthesis and Impacts on Sustainable Adoption Integrated*, the discussion shows that the obstacles of cost, diminishing returns, and organisational capability are interrelated. High initial effort leads to low levels of general use, low maintenance levels limit learning accumulation, and weak organisational capability also weakens sustainability. The results indicate that an incremental architecture-aware and organisation-embedded approach can potentially break this situation without unnecessary capital commitment. Instead of endorsing detailed or advanced SC and TD methods, the results would lean toward selective usage, modular re-use, and knowledge-based learning. This reframing helps focus analytical effort toward decision value, spreads learning over product generations and helps to eliminate organisational resistance. From an academic point of view the conversation helps us not think of SC and TD as static instruments for an enterprise, rather it helps us to appreciate that such tools and

implementations are both evolving practices that need to be scoped, institutionalised and interpreted in complex industry environments in order to be effective tools to utilise.

5.6 Discussion of Results on Research Question Five

RQ5: In identifying methodologies to resolve the problem of RRR (Reverse Referencing Risk), which consists of incorrect assumption of Should Costing/Tear Down that same/similar product, this is the same manufacturing process (Longauer et al., 2024). Describe the cases when “same process policy” is applicable and when it should be reconsidered to see what type of manufacturing the actual process is. This results for this paper places Reverse Referencing risk (RRR) as an inherent methodological issue in Should Costing and Teardown practices in the networking industry. Instead of being created due to isolated analytical mistakes, RRR is the systematic byproduct of inference costing, and due to the lack of production data against suppliers, analysts rely on physical similarity, architectural similarity and historical benchmarks (Gillis and Pahl, 2010). The results show that the dependence, though operationally convenient, results in structural risk of misinterpretation since product similarity can become mistaken for manufacturing parity. The literature-based findings suggest that RRR is particularly widespread in networking products due to their modularity of platforms, standardised form factors, and the need for re-using of external interfaces. These properties generate strong visual and functional continuity between products, further promoting the use of reverse referencing. However, the implications of findings show that this continuity does not disguise considerable divergences in the methods of manufacturing, especially in power electronics, optics, and advanced PCB assemblies. The PSU case study is an empirical validating of this dynamic: it indicates that externally indistinguishable products can manifest materially different internal architectures and process choices. A key interpretation of the findings is that the assumption of “same process” is not intrinsically

inaccurate, though it is often applied beyond its permissible boundary conditions. The case makes it possible to assume process equivalence when multiple stabilising conditions are present at once. These are supplier continuity, manufacturing site consistency, mature production status, unchanged electrical topology, and stable automation levels. In this light, the teardown evidence showed alignment in soldering methods, transformer construction, PCB stack-up, and thermal attachment strategies. Against such tightly controlled backgrounds the use of historical cost models is supported by physical and architectural validation, and reverse referencing becomes an analytical shortcut rather than a distortion. Yet the findings also show that these conditions are brittle and easily broken.

Internal process divergence may occur when external form factor, wattage rating, and interface specifications do not change in any specific case owing to changes in efficiency targets, reliability expectations, or supplier process transitions. At the PSU step, the non-linear increase in the complexity in the process was seen because the transition to higher efficiency classifications involves even more challenging magnetic designs, tighter tolerances, and reduced yield stability. Such modifications were not observable upon external examination, and would not have been noted under a naive reverse referencing strategy. This observation highlights the point that manufacturing has largely reacted to performance and risk needs, rather than outward appearance of similarity in product. The investigation also indicates that RRR is increased through the temporal replication of cost models between product generations. The implementation of automation improvements independently within the same supplier organisation resulted in alterations to labour content and cost structure were sufficiently significant that previous assumptions were violated as suggested in the case study. This implies process equivalence is not only supplier specific but time-dependent. As a result, reverse

referencing that fails to take account of process evolution threatens to entrench old assumptions into the existing cost models, which will subsequently systematically under- or over-estimate. One key tenet of the results is the limited contribution of expert interviews to this research question. Though none of the interviews provided detailed new RRR specific insights, there is a great deal of information to be gained from their absence. It implies that RRR works as a latent threat in the organisational way of working rather than as a deliberately identified problem faced by practitioners. This finding further supports the interpretation that RRR endures not due to being unknown, but because it is normalized, due to defined costing workflows and constraining time. By doing so, the PSU case study is important in calling an otherwise latent hazard to the attention of the broader public.

The ways suggested to minimize RRR, as described in the results, represent a re-orientation of product-dominant to process-dominant thinking. Process signature mapping, DSM-based cross-validation, and multi-dimensional cost driver decomposition all problematize the assumption that visual similarity is a reliable proxy for manufacturing equivalence. These methods are not removing inference but they discipline it (applying explicit/conditional (rather than implicit/absolute) premises to assumptions) This difference is crucial because it increases both the accuracy of analytical analysis as well as the credibility of the organisation. The use of confidence-banded cost ranges further mitigates one of the most damaging consequences caused by RRR: false precision. Since cost models unambiguously indicate uncertainty where process equivalence hasn't been confirmed, it shifts the model from being a statement of pseudo-exactness to a decision-support tool. The approach is aligned with broader findings about analytical humility in the study, while also strengthening trust in should-cost outputs, both internally and in supplier-facing areas. At the end, the discussions

suggests that the successful management of RRR is a more organisational capacity issue than this methodology problem. Cross-functional validation, for instance the combination of manufacturing engineering, quality and supplier management is essential in order to test reverse referenced assumptions. Learning loops from the findings indicate that organisations may be able to reduce RRR through institutionalisation of feedback from incidents of erroneous assumptions. This iterative learning process is very different from an idealised notion of complete transparency and provides a more plausible approach towards increasing the robustness of costing in sophisticated supply chains. In conclusion, their findings indicate reverse referencing risk is induced when product similarity is mistakenly construed as manufacturing equivalence. The “same process” assumption is appropriate only where an operation is of sufficiently limited and verifiable nature (ie, where process stability and maturity are stable). In that context, deviation in performance requirement, supplier context, automation level or lifecycle stage requires reanalysis of manufacturing processes. Rather than abandoning referencing completely, addressing RRR therefore demands disciplined validation logics, explicit management of uncertainty, and organisational learning mechanisms. This interpretation goes further than what Longauer et al. (2024) and bases in real evidence from the networking sector.

5.7 Discussion of Results on Research Question Six

RQ 6: What are legal, ethical and IP Issues while doing Should Costing and Tear Down?

Themes in discussion The section presents the results of Research Question 6, which included the investigation of the legal, ethical, and Intellectual Property (IP) issues related to using Should Costing (SC) and Tear Down (TD) analysis in networking. Based on literature and results from the interviews with panelists featured in Results, why these issues emerge, how they inform the way organisations act and what they suggest for the responsible use of SC and TD in operations is explained. An essential result of the above

results is confirmed that SC and TD are situated in a legally and ethically unclear space especially in technologically complex and supplier-oriented sectors like networking. Overall, the results support previous claims that these approaches are fundamentally different from conventional cost accounting by involving reverse inference, instead of using the disclosed cost information (Porter, 1985; Sandborn et al., 2010). The reverse inference feature explains why legal, ethics, and IP are not peripheral issues but structural constraints in the analysis, affecting the ability and depth of the analysis itself. The literature review demonstrates that reverse engineering of legally obtained goods is generally allowed in theory, but the interview findings suggest that the legality in application is far more ambiguous in practice. Intervening interviewees repeated again and again that contractual obligations, rather than statutory law, is the primary source of legal risk.

This is consistent with Shank and Govindarajan (1993) who point out that strategic cost practices are often subject to relational and contractual limitations rather than technological viability alone. Thus, the argument goes, legal permissibility is not as being the binary but a negotiated and situational condition, as defined by supplier contractual provisions, licensing conditions, and regional jurisdiction differences. This heterogeneity also further complicates matters among global networking enterprises, and is what makes firms' approaches to teardown conservative or inconsistent in different regions. The issues of intellectual property were then highlighted as a separate, but closely interconnected aspect of risk. Whereas previous literature focuses on the risk of teardown revealing patented characteristics or trade secrets, the interview results contribute to this interpretation by underlining how the value in integration-level IP is growing in modern networking devices. As component engineer respondents observed, now differentiation lies at packaging strategies, in calibration protocols, and system-level integration rather

than at a discrete components level. This supports Bengü's (2010) assertion that advanced manufacturing enhances the opacity of IP borders, which makes it hard to ascertain when cost analysis becomes the illegitimate extraction of knowledge. The question emerges that this ambiguity results in an organisational caution and it can justify the tendency to minimize the depth of the teardown, however at the cost of losing analytical value. Ethical issues, which are not as explicitly legislated as legal or IP risks, were found to strongly condition the perception of and use of SC and TD. The results validate Riley's (1987) distinction between cost understanding and price enforcement, and indicate that ethical tension follows when the two become intertwined. The interviewees' focus on erosion of trust and defensive supplier behaviors support prior literature on strategic cost management that cautions negative implications of hyper-fascinating cost transparency over long-term collaborative efforts (Shank and Govindarajan, 1993).

Finally, the findings underscore that ethical risk is not limited to external supplier relations. The report also highlighted internal ethical risks (i.e., the presentation of teardown derived estimates with false precision). This finding carries forth Cooper and Kaplan's (1988) criticism of the misappropriation of cost measurement that ethical questions can be raised even prior to engaging suppliers, at an internal level in decision-making. A significant contribution of the findings of the interviews is to highlight the extent to which legal, ethical and IP considerations influence how extensive and frequent SC and TD are used. Instead of serving as theoretical constraints, these concerns drive the methodology (eg high-level architectural analysis vs virtual teardown approaches) decisions. Manufacturing and procurement respondents recognised that these adjustments reduce analytical precision, but considered this to be an acceptable trade-off to maintain compliance and stable relationships. This is characteristic of a wider practice gap evident

in the SC and TD literature as a good balance between methodological rigor and organisational risk-taking approaches is often ignored. As we do not yet have a substantive case study for our research question, we only reinforce the findings that we identified further and not make their weakness stronger. This lack of an observable outcome at the case level is itself indicative of the chilling effects of legal and ethical uncertainty to experimental SC and TD exploration in the empirical field. This aligns with an interview-based observation that organisations often restrain or abandon teardown before they are developed as well-documented, practical case studies resulting in disjointed learning and undercooked institutional capacity. Lastly, the debate emphasises that governance functions are enablers not limits. These approaches highlight that both early engagement of legal and compliance functions, control over teardown-derived knowledge, and defining clear analytical bounds that are acceptable are needed to maintain practices around SC and TD by examining results from both literature and interviews. Rather than entirely eliminating risk, however, the mechanisms suggest, what the Results chapter considered to create a “safe operating zone,” in which SC and TD can create value without provoking legal fights or ethical challenges. It’s clear that this ability to govern might be a point of competitive advantage in its own right for the networking industry, where supplier ecosystems are heavily concentrated, and innovation itself is highly interdependent.

To put the conclusion in simple words, the debate illustrates that ‘legal, ethical and IP issues are not secondary challenges to be resolved post-technical analysis, but underlying issues underpinning whether And to what extent Should Costing and Tear Down should be used at all. The results indicate that a responsible use of these methods needs to be done in such ways as to be not only analytic smart but also legally literate, ethically conscious and organisations should come equipped with adequate maturity as well. This

is consistent with the logic espoused in RQ6: while they have analytical potential, SC and TD are not only not applied equally across the networking industry, but their implementation is inconsistent.

5.8 Discussion of Results on Research Question Seven

RQ7: How do we use Costing and Tear Down in a supplier collaboration approach and not as a supplier backlash with stiffening of relationships, which is currently one of the most critical issues (Longauer et al., 2024) about wider acceptance of Should Costing and Tear Down methods in Networking industry?

The results from the review of literature, expert interviews and in particular the PSU case study also indicate that Should Costing (SC) and Tear Down (TD) are not simply monolithic approaches to the same purpose with the same results, but flexible analytical practices that rely heavily on organisational intent, governance and relational context for their effectiveness. Although the computational power to decompose products and create cost models is well established across networking in general, the main strengths and limitations of these methods depend on how such strategies are framed, articulated and integrated within supplier engagement, rather than their methodological precision. SC and TD were strong instruments of enhancing cost visibility and to open the door for design-for-cost discussions across all of the data sources. Yet such advantages are constantly negated by the threat for supplier opposition, trust erosion, long-term relationship damage if the methods are implemented adversarially or singularly. This duality helps to explain why SC and TD are still not uniformly used across networking organisations at the organisation level even though they are both growing mature and having a use that may be more relevant to high-risk bargaining than more average decision making. Our literature review suggests that supplier pushback is not a structural response to cost transparency but is a reaction to perceived intent. Suppliers

perceive SC outputs as vehicles of margin extraction where SC outputs represent set price targets that cannot either be explained, interpreted or interpreted as indicative analytic estimates. Indeed, the interview findings underline this interpretation, especially from procurement and commodity management respondents who noted that suppliers often equate should-cost models with predetermined commercial outcomes. This attitude erodes trust and embeds defensive behaviours, such as lower transparency and a refusal to share learnings from manufacturing. One of the main benefits of SC and TD gained from the interviews (and case study) is that it enables cost learning, rather than price enforcement. In turn, when reframed from “should cost” to “could cost”, these methods remove the concern at compliance and focus on exploration. This shift opens the door to conversations about cost drivers, specification trade-offs and process constraints, vital in networking products with narrow performance margins and demanding integration. Respondents from the Design and Component Engineering domain invariably pointed to the fact that SC and TD are most useful when it is useful for guiding design decisions from the top of the product life cycle, and not as a tool for negotiation post-design. However, one significant disadvantage, as noted throughout the observations, is that SC and TD have a tendency to overgeneralise on manufacturing situations when uneducated/processed.

Product Manufacture experts observed that teardown-based assumptions frequently do not capture yield variation, capital amortisation and the learning curve impact. It's this disconnect that feeds supplier scepticism and feeds into the belief that cost constraints are unrelated to operational real-world challenges. The PSU case study illustrates how this disadvantage can be reduced by promoting joint teardown activities, and providing suppliers with the opportunity to contextualise what is perceived as a design and process decision that comes into play. Further, the case study illustrates that teardown analysis

can serve as both a relational destabiliser and a collaborative enabler. Conventional “black-box” teardowns are unilateral in nature and elevate suppliers’ worries about the intellectual property exposure and dual-sourcing risk. In contrast, the structured, selective approach to teardown used in the PSU case enabled effective cost drivers to be understood while preserving the supplier-differentiating knowledge. This finding suggests that the benefit of TD may not be in total disassembly, but in focused analysis, based on a common aim. Another valuable insight from the interviews is the function of temporal separation between analytical and commercial phases.

Regardless of how reliable the models, when SC and TD outputs can immediately be translated to price demands, suppliers react defensively. Uniting cost discovery and negotiation means analytical results can be assimilated as engineering documentation, rather than negotiating positions. External experts constantly cited this separation as a key characteristic of organisations that adopt SC and TD more often and with a decrease of relational friction. In terms of organizational analysis, the findings show that the benefits of SC and TD can only be achieved when internal alignment occurs ahead of supplier involvement. Cross-functional misalignment — especially one defined between procurement-driven cost targets and engineering-driven performance demands — diminishes credibility and fuels supplier push back.

The interviews suggest SC and TD are most effective when held as a unified organisational position, as in which technical rationale combined with manufacturing understanding and commercial strategy together form the common base from which each can work. Though there are opportunities for cooperation, these findings also reveal some severe caveats. Collaborative SC and TD application is not available for all supplier relationships. Strikingly differentiated suppliers with proprietary practices and/or alternatives with few marketplaces of competition maintain structural power against

transparency no matter what type of engagement. In those types of circumstances, the drawbacks of SC and TD — such as strain on the relationship and a lack of actionable insight — outweigh their potential benefits. This supports the view of SC and TD as contingent tools, which can be developed according to product criticality, supplier dependency, and lifecycle stage in addition to generalization.

All the above implies that the modernisation of the techniques of Should Costing and Tear Down in the networking industry provide significant analytical benefits, but also present significant relational risks. Their utility is less a function of methodological complexity and more as a function of governance and ordering decisions, and behavioural framing. If framed as collaborative mechanisms for learning and applied incrementally, SC and TD may increase cost transparency, design decision-making, and engage with suppliers. When enforced coercively or without relevant contextual understanding, they have the potential for perpetuating adversarial dynamics and potentially limiting their very utility in the long term. This read is consistent with the barriers of adoption outlined in the literature and explains why SC and TD despite their technical maturity experience resistance in practice. The findings thus imply that enhancing SC and TD effectiveness in the future will likely be through organisational and relational innovation rather than ongoing improvement of analytical models.

CHAPTER VI: SUMMARY, IMPLICATIONS, AND RECOMMENDATIONS

6.1 Summary

This study aimed at a systematic application of Should Costing (SC) and Tear Down (TD) analysis to investigate the identification and quantification of essential cost drivers in networking products. The study was structured around seven questions with related themes, covering technical, organisational and relational facets of cost analysis literature at the time. Utilising literature analysis, expert interviews, and case studies on optical transceivers and PSU modules, this research aims to offer empirical as well as theoretical implications on how SC and TD techniques are employed and challenges they encounter and how they can be improved. The first research question consisted in evaluating various SC and TD techniques available in the networking domain, including their strengths and weaknesses. The findings indicate that SC and TD work as flexible analytic frameworks as opposed to unidimensional methodologies. Physical teardown is the basic technique and shows the material composition, assembly methods, and high-density combination methods. But conventional physical teardown is not enough to learn non-physical cost drivers like firmware, proprietary calibration processes and complicated testing routines.

Functional and architectural decomposition techniques using models (most prominently based on Design Structure Matrix (DSM) frameworks) enable comparison of cost drivers and system architecture, which leads to revealing dependencies that aren't apparent at a component level. Sophisticated reverse-engineering methods – to gain a closer understanding of the structures of silicon and its packaging technologies – require significant financial, ethical, and legal costs — making them not suitable for everyday application. Likewise, Should Costing models rarely be used independently, bottom-up, parametric, hybrid and AI-augmented approaches are mixed in practice to achieve an

analytic depth while keeping it cost appropriate. In summary, the study suggests that cost analysis results depends not on the technical power of a single approach but on judicious choice and integration techniques, and adaptation to the organisation. The second research question examined how teardown analysis can be used within a system to help identify and estimate cost drivers. The evidence provides the advantage that systematic teardown is more effective when it is designed as a staged and theory-driven process that moves forward from product selection and scope definition to physical disassembly to process inference and functional decomposing to cost driver quantification. Although the first order drivers—including component counts, material choice and packaging methods, among others—were initially useful for providing initial insight, the higher order drivers, including manufacturing complexity, yield sensitivity, supplier maturity and architectural coupling, evolve only by means of structured inference and cross-functional analysis. Quantification consists not simply of enumeration, but uses hybrid methods where proxy metrics, parametric modelling, and time-driven activity-based costing are employed to predict relative cost impacts.

The optical transceiver case study illustrates the operationalization of this framework at work, illustrating how effective routine teardown can expose dominant cost drivers and offer credible input for internal decision making as well as supplier engagement. Issues are focused on the relevance of SC and TD tools and methods, the issue of expensive initial investment, diminishing returns and organisational capacity constraints were addressed in research questions three and four. The research concludes that no single tool or method is adequate; incremental, modular, and architecture-aware approaches are consistently the most actionable and meaningful. The complementary capabilities of time-driven activity-based costing, learning-curve models, parametric estimation and hybridised teardown frameworks simultaneously increase the cost transparency whilst

also providing a way to manage resource expenditure. Large upfront costs are primarily structural, as detailed teardown and cost modelling requires labour and expertise. Yet these costs can be defused with tiered analysis, deep dives into crucial subsystems, and the use of teardown outputs over product generations. Organisational incapability barriers including not evenly sharing skills, fragmented ownership and cross-functional misalignment are still major obstacles. Implementing SC and TD outputs into current workflows and enabling the spread of knowledge through clearly visual and explainable models improve implementation and sustainability.

The fifth question was about Reverse Referencing Risk (RRR), which occurs if the analyst has an incorrect impression that a similar product is manufactured in the same way because of the manufacturing process. It shows that RRR does not inherently pose a risk when the “same process” assumption is used among rigidly delineated settings such as stable suppliers, mature production processes, identical level of automation and the same electrical topologies. But the performance requirements, supplier processes, and lifecycle stages vary, which can invalidate these assumptions. So the study emphasizes the importance of rigorous validation or validation of a process signature map, confidence-banded cost ranges, and feedback between the organisation to address RRR, transforming RRR as an underlying organisational risk to a controllable analytical variable.

The sixth research question addressed legal, ethical and intellectual property issues. SC and TD exist in a grey regulatory and contract-based domain, in which it is possible (with the theoretical permission) to reverse engineer legally sourced products, from the outset this may not exist in practice due to supplier contracts, licensing contracts and local laws. Intellectual property threats are not confined to specific entities but also to the entire system and proprietary calibration methods and systems, so careful interpretation and

conservative application of teardown findings are desirable. When this occurs, ethical concerns arise as analytical outputs are misrepresented or co-opted, potentially damaging trust with suppliers or the organisation itself. It can be deduced from the recommendations that effective governance, as well as early engagement of legal and compliance teams, access control of sensitive data, and setting clear analytical thresholds, can ensure SC and TD practices are value added in a compliant and ethical manner. Overall, the seventh research question related SC and TD from a more strategic perspective of supplier collaboration rather than resistance. Strategy-led: positioning these methods as co-operative, learning tools (rather than as means to margin extraction) enhances supplier acceptance and trust substantially. Incremental teardowns, supported communication on cost drivers and time-based separation of analysis and negotiation give a context to suppliers, make them perceive lower risk and enable for co-decision making. In contrast, unilateral or adversarial use of SC and TD can reinforce defensive behaviour, limit transparency, and negatively impact long-term supplier relations. Aligning the organisation around the idea of one common culture (with procurement, engineering, and manufacturing) is key against the backdrop of dissonance in terms of the message and any conflict that might harm in relationship. Summing up, this study claims that SC and TD approaches are better conceived of as dynamic socio-technical competences than as static technological instruments. Their effectiveness is based as much on organisational integration, governance and relational framing as on analytical sophistication. Throughout the seven research questions, the key themes are methodological pluralism, cross-functional engagement, modular and architecture-aware approaches and attention to legal and ethical boundaries. Structurally, and at the bottom-up, these approaches provide organisations with credible and decision-useful analytics of high-value cost determinants in a way that is structured and relational through a

systematic integration of physical teardown, functional decomposition, process inference, hybrid cost modelling, and cost analytics.

From early design tradeoffs to supplier negotiations, these insights apply as a basis for embedding SC and TD as strategic capabilities for high-tech networking organisations at every level of the decision-making process. Theoretically and in practice, the study adds something to the body of literature by showing that SC and TD are of more significant value than how much costs are incurred and valued in the immediate context. As systems of organisational learning and relational negotiation and strategic cost transparency, they demand integrative, context-sensitive and knowledge-focused methodologies to contemporary cost engineering. Incorporating these lessons across activities will enable organisations to build “overhauled” tools that transform isolated analytical exercises into synergies to the end-users, creating source of competitive advantage that in turn drives designing, procurement, and supplier collaboration in an increasingly intricate technological environment.

6.2 Implications

The results of this study have far-reaching implications for networking practice as well as theory on Should Costing (SC) and Tear Down (TD) methods. The main implication pertains to the concept of SC and TD as more of a socio-technical competences than purely technical features. "Analytical rigor is needed, not sufficient to create value, without an overall organisational maturity, cross-functional integration and clear governance." This practical implication points out that companies should not expect to only adopt advanced teardown processes or bottom-up costing methods but must also develop distributed talent in the fields of engineering, procurement and manufacturing functions. By integrating SC and TD outputs into existing corporate decision-making processes—from design reviews, to sourcing assessments, to supplier discussions—

organisations can advance such practices from episodic and labour-intensive exercises into enduring mechanisms that cumulate learning over several product generations. This study illustrates a secondary major implication, concerning the allocation of resources and the analytical extent. The very structural traits of networking products, namely high-value concentrations among limited numbers of components, modular architectures, and agile technology processes, render full usage of SC and TD methods both expensive and of decreasing marginal value. Expert interviews and case studies suggest that tiered, modular, or architecture-aware approaches provide significantly higher analytical impact than effort.

Focusing on critical subsystems with deep teardown analysis, and on applying parametric or benchmark-based methods to less critical modules, allows organisations to balance their use of resources while maintaining quality of insights. From a strategic viewpoint, this implies that the cost engineering teams should take a step-wise and prioritised design approach to analysis that maximises intensity of analysis for decision criticality, product complexity, and market timing. A third implication has to do with managing non-physical cost drivers: firmware, system-level IP, proprietary calibration routines, etc. The research proves that traditional physical teardown is not sufficient to include these components at present, although they account for a significant part of product cost for advanced networking devices. Hence, organisations have to supplement SC and TD with process inference, parametric models, and expert judgement. At an operational level, this hybridisation leads directly to changes in team composition, demanding collaboration across mechanical and electrical, and software domains. From an academic perspective, this suggests that the approach developed for the future should be integrating frameworks that can align for tangible with intangible cost drivers without sacrificing traceability and defensibility of the cost estimates.

RQ5 has further organisational practice implications. The results show that the assumption of an “same process” based on product similarity is only true under well defined and stabilised conditions. Therefore, professionals need to have a disciplined validation logic and confidence-banded cost ranges, alongside cross-functional feedback loops to reduce the occurrence of erroneous assumptions. This need highlights the importance of organisational culture and governance in sustaining reliable cost estimations. Companies that weave into their processes iterative mechanism for validation that involves testing and updating assumptions in real projects and different product generations will be able to minimise systemic errors and increase the credibility of SC and TD outputs for both internal and external stakeholders.

Legal, ethical and intellectual property (RQ6) add layers of organizational complexity. The study highlights that SC and TD function on a complex legal- and ethics-laden ground, especially when reverse-engineering and a teardown are practised without full visibility or permission to contract. Organisations therefore need governance mechanisms that describe acceptable analytical boundaries, protect proprietary information, and ensure adherence to local regulations. Incorporating legal and compliance oversight as part of our SC and TD workflows moves away from constraining constraints and into enabling frameworks, so that we are able to operate in a “safe operating zone” for cost analysis. The ramifications are both tactical and strategic: companies that manage the risks effectively in these areas can use the takeaway from the assessment to bolster supplier negotiations, design for cost optimisation—as companies that can learn from the lessons learnt and internal cost transparency, without compromising intellectual property or relationships.

Seen from a relational perspective, the findings of the study concerning supplier collaboration demonstrate that SC and TD are not just tools to capture cost insight, but rather tools of communication that establish trust relations (RQ7). This relational framing of SC and TD has a strong impact on supplier behaviour, in that adversarial positioning often induces defensive responses, lowers transparency, and encourages IP-protective behaviours. On the other side of the coin, collaborative, guided and incremental teardown activities can improve mutual understanding of design and process decisions, promote joint problem-solving and develop long-term relational capital. For organisations, this suggests that SC and TD are not merely technical interventions and that their deployment involves a strategic interplay between timing, sequencing and presentation to ensure that analytic outputs are not seen as tools of enforcement, but constructive tools for learning. Lastly, the study has wider implications for the design of organisational learning frameworks. Rather than treating teardown and cost analysis outputs merely as snapshots of emerging knowledge assets, organisations can take on longitudinal cost learning, ameliorate diminishing returns from repeated exercises, and entrench capability across functions. This view is consistent with learning curve theory and supports the move from a static view on cost modelling into adaptive, architecture-aware, and knowledge-centred SC and TD approaches. Together, and with these impacts as an overall theme, this suggests that the successful organisations will be those which marry technical know-how with governance, relational literacy, and intergenerational learning, transitioning SC and TD from episodic interventions to the sustainable sources of competitive advantage we want.

6.3 Suggestions for Further Research

So, although this study offers a systematic empirical account on how teardown analysis and should costing could be systematically applied to identify and measure cost drivers in the networking products, it suggests some gaps in the research that must be filled, albeit at a given moment. These recommendations reflect not only methodological shortcomings, but also the organizational practices, systemic changes in networking technologies, and new legal and ethical constraints increasingly influencing what is analysed in cost analysis. A first meaningful pathway for future research is extending the spectrum of cost analysis for teardown into software-based or cyber-physical networks. A recurring theme to the study results is that teardown analysis is strongest in identifying physical, architectural, and process cost drivers, while gaining less and less effectiveness with the value shifting from hardware to firmware, embedded software, calibration algorithms, and digital enablement layers. Modern networking products depend more and more on software-defined functionality, field-upgradable firmware, and cloud-managed control planes, which substantially contribute to lifecycle cost but remain largely unheeded in traditional teardown techniques.

Future studies might further develop hybrid analytical frameworks that marry teardown-based physical insight with software cost estimation approaches such as function-point analysis, feature-based costing, and model-based systems engineering (MBSE) methods. One such effort would be particularly useful to consider how to translate software development costs to shared costs for modular hardware platform sharing, a common complaint made by industry practitioners but not found by most of the cost engineering literature. A second direction for future studies, has to do with the longitudinal use of teardown analysis from all product generations. This study is cross-sectional of any single product or product family at a single point at a particular time. According to expert

interviews and observation of case studies, however, many of the key, important cost drivers—like supplier learning curves, yield stabilisation, architectural reuse—only become visible when teardown outputs are contrasted across successive rounds of design iteration. In future research, thus, longitudinal research design could be utilized to investigate cost drivers generated from teardown across product refresh cycles or changes in technology nodes or regional variations in manufacturing. It would build a better understanding of cost drivers, whether they persist or decay, enabling companies to separate the structural cost disadvantage from the ones that naturally tend to decline when learning and mass-scale effects occur. Related to this is the opportunity for studies in the future to examine the place of teardown in early design and architecture stage decision-making.

The current study specifically investigates teardown as a retroactive or contemporaneous analytic, where the analytic is conducted post product release or supplier negotiation. But a number of interviewees cautioned that such teardown-derived lessons, once institutionalised well, can be used to advise design-for-cost guidelines, platform reuse strategies and make–buy decisions in earlier stages of product development. Future analyses may investigate how historical teardown libraries, cost driver databases, and architectural dependency maps are implemented in design institutions and whether their integration has a measurable impact (or not) on early trade-off decisions. Indeed, empirical comparisons between design outcomes in mature teardown knowledge repositories and those lacking such knowledge repositories that are capable of generating causal evidence, in addition to descriptive evidence, would likely be useful. A further important aspect for future research is the growing application of digital, non-destructive and data-centric methods of teardown. As existing legal, ethical, and intellectual property barriers constrain the levels of physical disassembly that companies are willing or able to

undertake, other approaches such as X-ray imaging, CT scanning, digital twins and AI-assisted component recognition are emerging. Though these systems can boast scalability and lower compliance risk, few studies studied their accuracy, reliability, and interpretability. Further studies could systematically examine the accuracy and precision of what has been deduced to be costing variables from physical teardown or from digital teardown or virtual teardown, and compare the degree to which cost drivers derived from non-destructive approaches match up with operational manufacturing processes and costs. These studies would be relevant in regulated industries and cross-border sourcing contexts, where physical teardown can be restricted by contractual or jurisdictional factors. Further research is also encouraged in the organisational and behavioural aspects of teardown and should costing adoption. The results of this study highlight that analytical capability alone is insufficient for the practical utilisation of teardown-derived information.

The credibility and use of cost analysis outputs is often compromised as a result of cross-functional misalignment, skewed technical literacy, and mismatched incentive structures. Future research could therefore build off organisational theory or behavioural economics perspectives to consider how teardown, and should costing, practices are interpreted, contested, or resisted within firms. Further qualitative inquiry into what is at stake is needed to better understand how technically sound analyses may not always make a difference, through processes like decision-making, power relations between procurement and engineering functions, managerial framing and acceptance of cost insight. Also, the supplier-facing effects of a teardown analysis warrant more study in future works. But although it shows this can be done transparently and stepwise and can provide support for collaborative supplier relationships through teardown-based cost analysis, it does expose

risks that remain if the underlying practices are undermined by mistrust and defensive behaviour.

Further studies could investigate supplier perceptions of teardown in other cultural, regulatory and market contexts and how those factors – scale of supplier, dependency asymmetry, and exposure to intellectual property – may impact responses to cost transparency promotion. The relative impact of contextual factors on collaborative cost analysis strategies would be useful and highlighted by regional comparisons (European, East Asian, and North American supply chains, respectively).

Ethical and legal issues represent another important dimension for future efforts. While this research highlights the critical issues of intellectual property, contract terms, and ethical use of teardown knowledge, it is important to note the ongoing fragmentation and dynamism in the regulatory environment on reverse engineering and cost analysis. In the future, legal and policy-related research could map differences in jurisdiction over potentially permissible teardown activities, consider how emerging regulation in digital product passports and right-to-repair initiatives may change the landscape of teardown cost analysis, and consider the extent to which this may expand or constrain the scope of teardown-led cost analysis. This type of work may prove particularly valuable in the context of the European Union, whose sustainability, transparency and policy agenda in the circular economy is increasingly shaping product design and supply-chain activities. Methodologically, future research could also examine formalised confidence and uncertainty representations in teardown-based models of costs.

A key theme also repeated in this study is the dependence on proxy measures, inferred processes and expert judgment for estimating higher-order cost drivers. Although such methods are crucial from a practical perspective, they introduce uncertainties that are not well-articulated to the decision-makers. Later works may want to investigate whether

explicit modelling of uncertainty through approaches like probabilistic cost range modelling, Bayesian updating, and scenario-based sensitivity analysis can influence managerial trust and decision-making quality. Last of all, some more study is probably needed to make the relationship between academic cost driver theory and industrial use more clearly clearer. Although this research shows that extended cost driver theory can apply to networking hardware, it also points to that practice does not consider theoretical language in practice in general. Possible direction for future research is to further develop practitioner-focused frameworks, tools or visual representations of cost driver theory (or some other set of workarounds) that are informed and rigorous, yet accessible. Research methodology of design science – iteratively creating and validation of practical artefacts in partnership with industry stakeholders – would be well aligned to achieving this goal. Finally, future research on teardown analysis and should costing in networking products need to push beyond single-focused methodological optimization to consider a broader understanding of technology diffusion, organisational dynamics, regulatory barriers and longitudinal learning effects. Through the consideration of these interlinked dimensions, future investigations will be able to leverage the findings from this work to enhance cost management models which are not only analytically rigorous but are organisationally embedded, ethically responsible and strategically relevant in an ever more complex and software driven networking environment.

6.4 Conclusion

The aim of that research is to assess what type of Should Costing (SC) and Tear Down (TD) is being used within the networking industry, what methodological, organisational, legal and relational barriers stand in the way of the effective application and to what extent these tools could be adapted to still be relevant to more complex product and supply-chain environment. By a blend of scoping review, expert interviews and research-

backed industrial studies, the research has worked to transcend normative support of cost transparency tools to give a deeper insight into the way SC and TD function in reality, where its benefits are achieved and what their limits are. One important conclusion from this research, the discrepancy of SC and TD adoption and episodic use of SC and TD in the networking industry can be ascribed not to analytical maturity. In fact, the study shows that the principles on which (overlapping) techniques underpin are well understood and can provide significant insight into cost drivers, architectural trade-offs, and manufacturing complexity with an approach to their effective execution. The recurring challenges with their usage come from a disconnect between traditional, universal uses of SC and TD and the economic, organisational, and relational context of modern networking product development.

High upfront cost, decreasing analytical returns, organisational capability gaps, reverse referencing risk, and legal and ethical constraints, the findings provide evidence that these are not independent hurdles to implementation, but interdependent features of the environment in which SC and TD are used. Any attempt at resolving any one of these issues in isolation is therefore unlikely to lead to sustainable improvement. As one example, reducing analytical depth to lower upfront cost may increase reverse referencing risk, whereas severe cost enforcement can erode supplier confidence (leading to less access to the process knowledge needed for accurate costing). The research therefore suggests that the effectiveness of SC and TD comes down less to methodological sophistication than to how analytical ambition is scoped, how learning accumulates over timescales, and how cost insights are positioned in the context of organisational and supplier relationships.

Another significant finding involves the kind of learning outcomes that can be produced through teardown analysis. This model results showed the main argument regarding the

issue of diminishing returns is not a fundamental learning exhaustion but rather a saturation of learning at the component level. As long as analyses are focused on repetitive counting of familiar instances, incremental understanding is limited. Yet, rephrasing teardown outputs back in terms of their architectural dependencies, process signatures and long-term cost determinants means meaningful learning remains, even for mature product segments. This implies that the value of SC and TD for the longer term is not the repeated bottom-up estimation but rather to have the potential to support cumulative organisational knowledge around how design, process and cost co-evolve across product cycles. The study also deduces that organisational capability is the main factor in how SC and TD become sustainable practices or an isolated expert activity. Fragmented ownership, variable technical literacy and poor cross-functional integration inevitably reduce both the ability to conduct and to have a stake in cost analyses. However, organisations that invest in cost capability, embed teardown outputs into existing governance systems and view cost analysis as a learning tool not negotiation trump card, will be those best placed to realise persistent value. This result substantiates the fact that SC and TD must be considered as socio-technical procedures rather than simply analytical instruments. On reverse referencing risk, the study argues that manufacturing equivalence (based on a product's similarity) is NOT always correct or applicable. In fact, its validity should depend on a narrow definition of the supplier continuity, process maturity, architectural stability, and temporal relevance. Without these factors, reverse referencing is itself a systematic distortion as opposed to a method of working less efficiently. It therefore indicates that disciplined validation, explicit uncertainty management and the implementation of feedback-based learning loops are fundamental to the minimization of RRR especially in modular and rapidly evolving industries.

Legal, ethical and IP aspects arise from this work as not simply peripheral limitations, but as core barriers, which determine the depth, pace, and character of SC and TD use. The study suggests that responsible uses of these techniques demand not only technical skills, but also legal literacy and ethical understanding and structures for monitoring governance that can define the limits of acceptable analyses. In the absence of such maturity, organisations risk overextending, putting at risk their relationships and the law, and underusing SC and TD thus sacrificing opportunity for insight. The idea of a “safe operating zone” for teardown-based analysis offers a helpful framework for framing the way value can be harvested without generating intolerable risk. The study finally argues that the contribution of SC and TD for supplier collaboration is contingent as opposed to universally applicable. These methods can be considered as robust facilitators for collaborative learning and cost optimization when applied openly, incrementally, and with a clear distinction between analytic discovery and commercial bargaining. But, used coercively or unsustainably or without contextually sensitive applications, they intensify adversarial politics and erode their own credibility. This dichotomy is why SC and TD are a cherished and a contested phenomena in the networking space. Ultimately, the study builds on what has been found elsewhere in the literature, by reframing *Should Costing and Tear Down* as practices that do not ‘stand still’ (as the use of analytic measures may be) but ‘develop’ in that they are contingent on scoping discipline, architectural acumen/awareness, organisational integration, and relational governance. The research provides a more refined account of the persistent misalignment between the theoretical promise of SC and TD and the uneven uptake in the industry by grounding theoretical concerns on evidence from the networking sector. Although the research is unfortunately limited by its qualitative focus, industrial focus and case, focus-based nature, these constraints have not affected its main contribution. Instead, they underline the need for

context-dependent research based on empirical knowledge on cost analysis practices, which have frequently been presented in more abstract or prescriptive terms. The conclusions given herein set the stage for research in academia and a reflexive industrial practice in the future. Ultimately, Should Costing and Tear Down still be the most useful instruments in the networking sphere, but its overall utility will now rest more on the flexibility, learning and ethics of organizational learning as a whole and on methodological restraint, not an outright imposition. Borrowed as an explanatory and not an enforcement tool, and included in a wider capability framework, those techniques might remain to play a part in promoting sound decision-making within an ever more complex and interdependent industrial context.

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APPENDIX A

INFORMED CONSENT

Research Title:

Should Costing” and “Tear Down Analysis” Evolving Methods for Communication Networking Product Industry

Principal Investigator :

My name is Baiju C Bose. I am a DBA learner at SSBM GENEVA. I am conducting a study and you are invited to participate.

Purpose of the Study:

This research aims to understand the latest practices and procedures in Should Costing and Tear Down Analysis methods, tools and procedures followed on Networking Products, identify the challenges involved, expose why these practices are not followed as regular processes in Networking Companies, rather as adhoc practices. The study aims to bring up incremental solutions to some of the challenges in Should Costing and Tear Down Analysis. Focuses on some of the key questions (Research Questions) and provides lights into the answers based on isiths gained from previous literatures, expert interviews and case studies.

Procedures:

If you agree to participate, you will be invited into a Zoom meeting or in person discussion. We will then discuss around selected Research Questions in Should Costing and Tear Down analysis. You can respond based on your career experience, practical case studies you would have handled, your perceptions, etc. The discussion would be conducted as an informal one, but some notes would be taken down by me only in the interest of the research. It will take approximately 15–20 minutes to complete.

Confidentiality:

All information you provide will be kept confidential and used solely for academic purposes. Your responses will be anonymized to ensure that no personally identifiable information is included in the study's results. The data will be securely stored and accessed only by the researcher and authorized personnel.

Potential Risks and Benefits:

There are no significant risks associated with participating in this study. Your participation will contribute to valuable insights into improving health insurance marketing strategies, which may ultimately benefit consumers and the industry.

Consent Statement:

By signing below, you confirm that you have read and understood the information provided above. You consent to participate in this study and allow the researcher to use your responses for academic purposes.

Participant's Name: _____

Participant's Signature: _____

Date: _____

Researcher's Signature: _____

Date: _____

APPENDIX B

INTERVIEW GUIDE

Start with mutual introduction. Brief about the scope of the research. Reassure the confidentiality. Then get into a discussion to gather information, thoughts, inputs and ideas about the 7 Research Questions as listed below.

Research Questions

RQ1: What are the Should Costing and Tear Down techniques/methods available today in Networking Industry? What are their advantages and disadvantages?

RQ2: How can teardown analysis be systematically used to identify and quantify key cost drivers in networking products?

RQ3: What are the most appropriate tools and methods on Should Costing and Tear Down suitable to products in Networking Industry, that provides incremental solutions to some of today's challenges in Should Costing and Tear Down?

RQ4: What methods could be adopted to address the high upfront cost and diminishing returns of Should Costing and Tear Down? Any incremental solutions possible here? How to overcome the Organization Capability Barriers that impede the frequent application of Should Costing and Tear Down?

RQ5: To arrive at methods to handle the issue of Reverse Referencing Risk (RRR), which is about wrong assumptions by Should Costing/Tear Down team about same/similar product is equal to same manufacturing process (Longauer et al., 2024). Define as to in which cases this policy of "same process" applies vs which cases it needs reassessment to find out the manufacturing process.

RQ6: What are the legal, ethical and IP concerns while doing Should Costing and Tear Down?

RQ7: How Should Costing and Tear Down could be effectively utilized in supplier collaboration as opposed to supplier push backs and stiffening relationships, which is at present one of the biggest challenges (Longauer et al., 2024) in wider adoption of Should Costing and Tear Down techniques in Networking industry?