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R&D Productivity

Dutch high-tech equipment industry

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Summary

R&D organisations face growing challenges as they navigate both internal business pressures and external market demands, resulting in increasingly complex performance expectations. The combination of intricate labour markets, rising engineering complexity, and rapid AI adoption intensifies the need for faster innovation while straining the available capacity. There is also a large demand for increasing the productivity, e.g., the recent Draghi and Wennink reports. However, the generic concept of productivity does not really seem to fit R&D.

R&D productivity is inherently context-dependent, requiring a shift from generic metrics to a framework that reflects the diverse intents of innovation work.

Our research addresses two central questions concerning R&D productivity within the Dutch high-tech equipment industry. The first research question explores how R&D productivity, as perceived by this industry, can be more effectively understood and integrated into the design, execution, and impact assessment of R&D improvement projects. We conclude that there is no universal definition applicable across all organisations or even within a single organisation's diverse portfolio. Instead, we reframe R&D productivity as a context-dependent concept. We propose a four-quadrant framework, comprising disruptive innovation, adaptive innovation, maintaining innovation, and optimising innovation. Each quadrant has a different need for productivity, reflecting the varying priorities.

Adopt the four-quadrant model and embed impact hypotheses to steer R&D improvement efforts toward meaningful, measurable waste reduction.

The second research question investigates how industry metrics can be tailored to better reflect productivity in R&D improvement projects. The findings indicate that no single, straightforward metric can comprehensively capture R&D productivity. Instead, the concept of waste reduction emerges as a practical alternative, and we propose to focus on the three factors from the waste reduction formula. We also propose to develop and evaluate an impact hypothesis at both the start and the end of R&D improvement projects.

Abbreviations

Acronym	Meaning
AI	Artificial Intelligence
FPA	Function Point Analysis
GenAI	Generative AI
MBSE	Model-Based Systems Engineering
OECD	Organisation for Economic Co-operation and Development
R&D	Research and Development
ROI	Return on Investment
SAFe	Scaled Agile Framework
SE	Systems Engineering
TSR	Total Shareholder Return

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1 Introduction

1.1 Motivation

The demand for higher productivity receives a lot of political attention. The Draghi report on European competitiveness [1] from 2024 concludes that Europe lags the US in productivity and needs to close the innovation gap. TNO Vector interpreted the Draghi report in the context of the Netherlands [2], concluding that while the country maintains comparatively high absolute labour productivity, its growth has been slowing for years and actually contracted in 2023 and 2024 [2]. To close the innovation gap and safeguard prosperity, the report emphasizes that the Netherlands must commit to a new growth path explicitly driven by labour productivity [2]. Crucially, the TNO Vector analysis identifies that Dutch private R&D investment is lagging behind its peers, relying too heavily on a narrow set of mechanical and electrical engineering companies and failing to adequately fund the later stages of applied research and scaling [2]. The letter from the Ministry of Economic Affairs to the Dutch parliament on the productivity agenda [3] from 2025, indicates that to maintain our prosperity, we will have to do more with fewer people; yet, the growth of our labour productivity is stagnating. The Wennink report [4] from 2025 comes to a similar conclusion: productivity growth is the only sustainable way to maintain and increase prosperity, wages, and public services.

We are interested in the impact of Research and Development (R&D) improvement projects in the Dutch high-tech equipment industry, especially in relation to productivity of their R&D organisations. Improvements in operational productivity of high-tech equipment is outside the scope of this report. In this report, we explore how we can practically use the “productivity” concept in the context of R&D improvement projects.

1.2 Research Questions

We have formulated two research questions:

1. How can R&D productivity, as seen by the Dutch high-tech equipment industry, be better understood and incorporated into the design, execution and impact measurement of R&D improvement projects?
2. How can metrics for industry R&D be adapted to reflect on productivity in R&D improvement projects?

1.3 Report Structure

We continue this report by first describing our information sources. In Chapter 2, we describe our review of the academic literature, and in Chapter 3 we summarize our interviews with the Dutch high-tech equipment industry.

Afterwards, we present the reasoning lines we have developed. In Chapter 4, we describe a framework that explains the influence of business strategy on the interpretation of the “productivity” concept in R&D. In Chapter 5, we discuss how to reason about productivity improvement by looking at waste reduction in the context of R&D.

In Chapter 6, we conclude this report with answers to our research questions and some directions for further work.

2 State of the Art

This chapter describes the first source of information for this project, viz., a literature review of the state-of-the-art. The following subsections group the main topics that we have explored and that feed into our project contributions in later chapters.

2.1 Productivity Terminology

Basic definitions for common terms in the field of productivity are provided in [5]:

Term	Description
Productivity	Relation between output quantity and input quantity.
Profitability	Monetary version of productivity, including the influences of price factors.
Performance	Umbrella term of excellence, including profitability and productivity as well as other non-cost factors such as quality, speed, delivery and flexibility.
Effectiveness	Degree to which desired results are achieved.
Efficiency	How well the resources are utilized.

The combination of high values of efficiency and effectiveness leads to high productivity.

Productivity is included in performance, which also considers quality. [6] states that “In most knowledge work, quality is not a minimum and a restraint. Quality is the essence of the output” and “Productivity of knowledge work therefore has to aim first at obtaining quality, and not minimum quality but optimum if not maximum quality. Only then can one ask: ‘What is the volume, the quantity of work?’ This not only means that we approach the task of making more productive the knowledge worker from the quality of the work rather than the quantity, it also means that we will have to learn to define quality.” According to [6], “Knowledge worker productivity is the biggest of the 21st-century management challenges.”

2.2 Organisational Productivity

The Organisation for Economic Co-operation and Development (OECD) provides two definitions of productivity [7]. The first definition of labour productivity is based on gross output:

$$\frac{\text{Quantity index of gross output}}{\text{Quantity index of labour input}}$$

The second definition is based on value added:

$$\frac{\text{Quantity index of value added}}{\text{Quantity index of labour input}}$$

The Draghi report [1] is based on the first OECD definition, whereas the Wennink report [4] is based on the second definition.

In the contemporary landscape, organisations often rely on financial metrics to gauge the success of these outcomes [8]. The Net Present Value (NPV) is frequently utilized to assess the potential profitability of R&D projects by calculating the difference between the present value of cash inflows and outflows over a period of time [9]. Similarly, the Compound Annual Growth Rate (CAGR) serves as a vital metric for understanding market trajectories in innovation-heavy sectors [9]. These metrics allow organisations to track growth stability and compare the return on innovation investments against other market opportunities.

Beyond pure growth rates, companies also utilize Revenue Multiples and Total Shareholder Return (TSR) to benchmark their innovation models against peers. Research into global innovation leaders identifies six distinct innovation models, indicating that "Creator" companies, those that disrupt markets, can achieve a TSR of over 20% (specifically 21.2% in the study period), whereas "Defenders" in mature industries often see significantly lower returns, averaging around 6.4% [8]. However, financial metrics often lag behind the actual work of R&D.

2.3 Multi-faceted Nature of R&D Productivity

Recent productivity research in software engineering demonstrates that no single dimension can represent productivity in complex knowledge work. Activity, output, flow, and satisfaction each reveal only one dimension of a multidimensional system. Attempts to collapse them into a single dimension consistently misrepresent the underlying concept [9]. Even in constrained environments, such as DevOps delivery, practitioners rely on a coordinated set of metrics rather than a single indicator.

The OECD defines productivity measures based on capital, capital and labour combined, and multifactor productivity. The OECD also states these measures are not independent of each other [4].

A framework for conceptualizing productivity in software development is presented in [10]. It consists of three main dimensions:

Dimension	Description
Velocity	How fast work gets done
Quality	How well work gets done
Satisfaction	How satisfying the work is

which can be viewed through different lenses, with the following four main types:

Lense type	Description
Stakeholders	Different stakeholders (e.g., developer, manager, vice president, etc.) may have varied goals and interpretations of any sort of productivity measurement.
Context	The project, and social and cultural factors will change perceptions of productivity. For example, is helping others considered to be productive?
Level	Scale of the group (e.g., individual developers, teams, organisations and the surrounding community) will lead to different perceptions of productivity.
Time period	Short term (e.g., days, weeks, or sprints) versus longer term (e.g., months, years, or milestones).

They notice that there may even be tensions between the lenses' notions of productivity.

In the realm of software and systems engineering, the industry has moved toward multidimensional frameworks to capture productivity more holistically. The DORA (DevOps Research and Assessment) metrics focus on flow and throughput, measuring outcomes such as deployment frequency and lead-time for changes. Recognizing that speed alone does not equate to productivity, the SPACE framework [9] was developed to capture five distinct dimensions:

SPACE dimension	Description
Satisfaction and well-being	How fulfilled, happy, and healthy one is
Performance	An outcome of a process
Activity	The count of actions or outputs
Communication and collaboration	How people talk and work together
Efficiency and flow	Doing work with minimal delays or interruptions

2.4 Productivity Metrics

The challenge of measuring R&D productivity is not new; it was identified more than four decades ago. For example, in 1982, Schainblatt observed that there were no systems for measuring the productivity of scientific and engineering groups without substantial flaws [11].

To address this complexity, Pappas and Remer advocated distinguishing between five R&D stages [12]:

- basic research,
- exploratory research,
- applied research,
- development, and
- product improvement.

Qualitative techniques (i.e., intuitive judgments) are used more frequently in the earlier stages, whereas quantitative techniques (i.e., generated numbers) are more common in the later stages. In the intermediate stages, semi-quantitative techniques, i.e., qualitative techniques converted to numbers, are most useful. Furthermore, the ideal system for measuring R&D productivity according to [13] should

- measure quality, quantity, and cost,
- be simple, and
- emphasize the evaluation of R&D outcomes rather than behaviours.

Despite the multi-faceted nature of R&D productivity, one simple formula appears everywhere. Across the literature, in engineering frameworks, and in management dashboards, productivity is consistently framed as output divided by input:

Productivity = Output / Input

Bloom et all [14] define productivity as the number of new ideas (output) divided by the number of researchers or effective research effort (input). However, relying on this ratio runs into the familiar problem that ideas are inherently hard to measure, underscoring a complexity in quantification that researchers have struggled with for decades [14].

To bridge the gap between daily engineering work and business value, techniques have evolved to measure and estimate output more directly. Early Source Line of Code (SLOC)

based forms like Constructive Cost Model (COCOMO) were shown to be inaccurate [15] compared to non-SLOC models like Function Point Analysis (FPA). FPA aims to measure the "function value delivered" to the customer independent of the technology used, effectively creating a dimensionless number to track output against cost and enable the estimation of new functionality [8]. This function-based measurement proved to be an effective way to compare productivity between projects, highlighting that the whole process, including the design phase, must be included to draw meaningful conclusions regarding productivity trends [16]. COCOMO II allows both SLOC and function points as input to estimate cost. COCOMO II evolved into Constructive Systems Engineering Cost Model (COSYSMO) [17] for systems engineering, using the number of requirements, interfaces, algorithms and operational scenarios as an input (like FPA more feature/function-oriented).

Agile development uses story points as a proxy for estimated size, and velocity as man-hours per story point, calibrating size and velocity at each sprint. Scaled Agile Framework (SAFe) development uses a more complex approach that uses the ratio between the value of a feature and the estimated size and risks to determine which job to do first, so-called Weighted Shortest Job First (WSJF).

To navigate the trade-offs between the various measuring approaches, Murphy-Hill and Wagner propose a taxonomy of techniques for measuring productivity that categorizes these metrics by their focus: outcomes, processes, people, or multiple dimensions, highlighting that no single category offers a complete solution [18].

Measurement category	Properties
Output/outcome-oriented	+ Relatively straightforward to measure quantities - Generally inadequate because they fail to take quality into account - Properties of the output may not reflect the difficulty of the task
Process-oriented	+ Partially automated measurement of time spent over activities - Fail to take quality into account - Difficult to determine which activities are value-adding
People-oriented	+ Matches worker's perception by focusing on self-determined goals - Low reliability (in case of both own and peer evaluation)
Multi-oriented	+ Measure multiple aspects of productivity - Collecting such metrics can be complex

2.5 Lean Principles

Measuring the productivity of software professionals is challenging and hazardous. The five principles of lean take an alternative approach [19]:

Lean principle	Description
Define value	Identify what the customer truly values in a product or service, distinguishing valuable activities from wasteful ones.
Map the value stream	Visualize all steps (both value-adding and non-value-adding) in the process to see where waste occurs.
Create flow	Make the value-creating steps flow smoothly and continuously without interruptions, bottlenecks, or waiting.
Establish pull	Produce only what the customer needs, when they need it, rather than pushing products through based on forecasts (a "just-in-time" approach).
Seek perfection	Continuously repeat the process, constantly looking for ways to improve value and eliminate more waste. (Continuous Improvement / Kaizen)

These principles are the foundation of SAFe [20].

[21] concludes that we do not need sophisticated productivity measures to recognize when time and effort are wasted. Waste refers to any object, property, condition, activity, or process that consumes resources without benefiting any project stakeholder. Reducing waste improves efficiency and productivity by definition. According to [5], waste can be considered to be the opposite of what productivity symbolizes.

To ensure that efficient work does not result in waste by building the wrong things, Innovation Accounting is employed. Originating from the Lean Startup movement, Innovation Accounting is a systematic process designed to track the progress of innovative ideas that face high uncertainty [22]. While traditional financial metrics (such as ROI or Net Present Value) are often unsuitable for managing early-stage transformation and can lead to poor execution, Innovation Accounting utilizes specific activity and impact metrics to bridge the gap between engineering work and business value. This framework facilitates fact-based decision-making, allowing teams to validate assumptions and de-risk projects early in the process [10], [22].

[6] states that work on knowledge-worker productivity begins with asking the knowledge workers themselves:

- What is your task?
- What should it be?
- What should you be expected to contribute?
- What hampers you in doing your task and should be eliminated?

Knowledge work heavily depends on tacit knowledge, i.e., knowledge locked inside the worker's head. As described in [23], knowledge work can also benefit from the lean principles. A substantial amount of knowledge assumed to be tacit doesn't have to be; it can be articulated and captured in writing if the organisation makes the effort to pull it out of people's heads. Even when knowledge is genuinely tacit, creating systems and rules to guide workers' interactions can lead to more-effective collaboration.

2.6 Artificial Intelligence

At the time of writing, the application of Artificial Intelligence (AI), Generative AI (GenAI) and Agentic AI is developing rapidly. The general expectation is that AI and GenAI will increase productivity, but we have found only a limited number of recent publications about this expectation. These publications suggest that the relation from the use of AI and GenAI to productivity is not so simple. For example, Generative AI can boost coding speed, but it can

also create dangerous technical debt introducing hidden cost towards the future [24] [25]. Companies are pouring money and effort into AI while overlooking a simple truth about adoption and governance: The real work happens at the team level [26].

[27] collects empirical data on the current uses of GenAI and assesses how this technology affects work productivity. Undeniably, while imperfect, these tools seem to enable individuals to focus on more complex tasks through automation. However, companies and individuals have difficulty assessing the human productivity improvements, because of the new competences needed to use GenAI tools and its impact on the workflow of teams.

[28] provides evidence that recent AI systems slow down experienced open-source developers with moderate AI experience completing real issues on large, popular repositories they are highly familiar with. Furthermore, they show that both experts and developers drastically overestimate the usefulness of AI on developer productivity, even after they have spent many hours using the tools. The authors stress that the observed slowdown does not imply that current AI tools do not often improve developer's productivity

The results from [29] reveal limited overall productivity change, highlighting the productivity paradox in which developers become faster but do not necessarily create better software or feel more fulfilled. Developers also mentioned trading manual coding time for reviewing, validating, and integrating AI-generated outputs. This trade-off raises a broader that the authors highlight: Does faster task completion truly represent progress, or merely shift effort without improving outcomes?

2.7 Systems Engineering

Systems engineering is included in this review because the literature on its return on investment provides one of the few empirical foundations for reasoning about R&D productivity in complex engineering organisations. Systems Engineering (SE) is defined by INCOSE as "a transdisciplinary and integrative approach to enable the successful realization, use and retirement of engineered systems, using systems principles and concepts, and scientific, technological and management methods" [30]. SE is based on systems thinking. Its practitioners take "a holistic, balanced, life cycle approach to support the successful completion of system projects[1]." [31] The ISO IEC 15288 [32] defines the SE processes and activities, the INCOSE Systems Engineering Handbook v5 [30] defines the "state-of-the-good-practice" for SE consistent with ISO IEC 15288 – these are 30 processes distributed across 4 process areas, the majority of which are performed iteratively, concurrently and recursively in or with participation of the R&D organisation.

Especially the technical processes are applied recursively onto the subsystems and subsystem elements until the level that they can be acquired or further designed and realized (either acquired or manufactured), as shown in Figure 2.12 of [30]. For complex systems, there can be multiple levels of system elements, with many elements at each level that in the end result in many parts that together comprise the product. R&D has to keep track of each of them, ensuring feasible functionality, performance, reliability, supply chain and manufacturing within the cost constraints.

R&D activities are thus fragmented across processes and activities, as well as levels and elements at each level (system, subsystems, components, parts) and multiple disciplines

[1] Note: both the term project and program are used in literature. In this section the project/program is used as in the referenced literature.

(project management, systems engineering, software engineering, other engineering disciplines, specialty engineering and many more). Each of these has its own processes, activities, methods and tools. R&D itself is thus a complex system with many interdependencies.

The contribution of SE to productivity was a topic of discussion already before 2000 [33]. In the early 2000s, investigations were started on the value of systems engineering [34] [35] [36] [37], resulting in an investigation into Systems Engineering Return on Investment [38] driven by Eric Honour. This resulted in multiple publications at INCOSE conferences [39] [40] [41] [42], culminating in a PhD thesis showing that Systems Engineering contributes to productivity by reducing program cost and schedule overruns [43].

Figure 1 based on Honour shows that investments in Systems Engineering have a positive Return on Investment (ROI) up to approximately 15% of effort across all investigated programs [43]. The recommendation is to spend 15% of the programme effort on Systems Engineering activities. In practice, 60-70% of the programs are below the optimum. This optimum percentage is related to the domain, a recent paper investigating the ROI of large infrastructure projects shows the optimum at 6.5% [44]. Also here, the current practice in is much lower with only 1.5% spent on Systems Engineering.

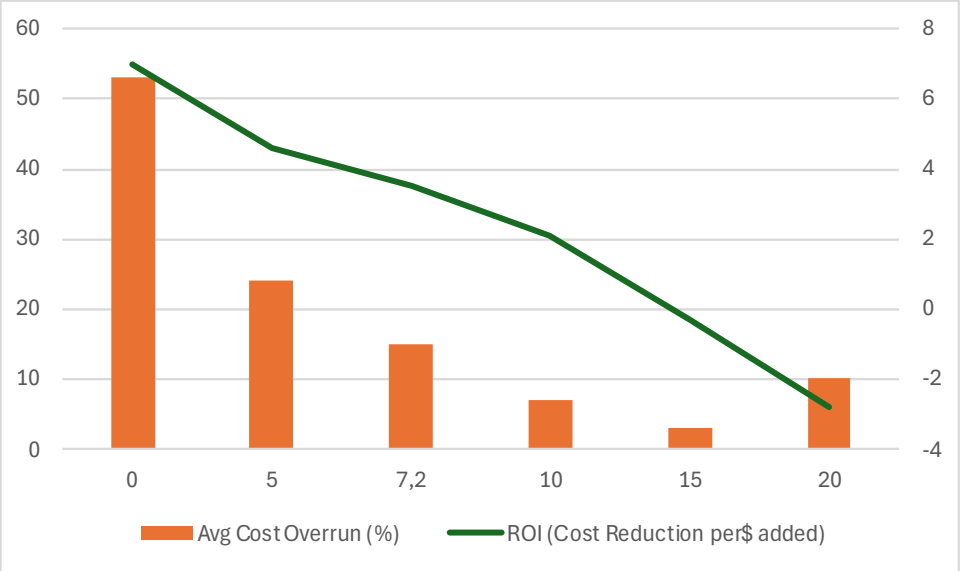


Figure 1: Optimal SE effort (% of program – left axis) vs Cost Overrun and resulting ROI (right axis) based on data from [43]

Systems Engineering effort is distributed across multiple activities. The SE-ROI study [41] describes the distribution of effort across 8 INCOSE-defined technical process categories as minimum, median and maximum across the investigated programs. Using the estimated medians from Figure 6&7 in [41] and normalizing to 100%, this leads to the distribution of effort in Figure 2. Honour's research [41] [43] shows that investing heavily in early SE activities (mission definition, requirements and architecture) and solid technical management strongly improves cost and schedule outcomes, while spending most effort on late-phase V&V offers little or negative ROI—early defect prevention and validation beat late detection and correction.

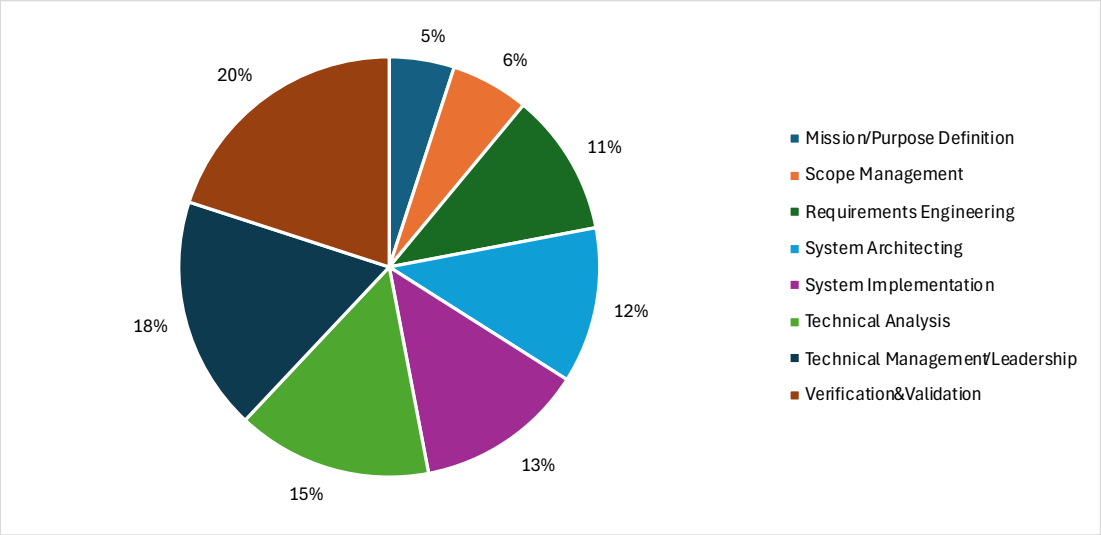


Figure 2: SE effort per activity category based on data from [41]

Combining this with the optimal SE effort of just below 15% [43], this means that no single SE activity will be more than 3% of the total program effort. ROI of investing in SE will mainly have to be achieved through the downstream effects.

The majority of program effort is downstream of SE Concept/Requirements & Architecture (Figure 3 based on [43]). The major benefit of SE ROI is reduction of downstream costs through risk reduction [41]. Systems engineering reduces cost through better understanding upfront and sufficient investment in early phases [45], confirmed in [46]. These downstream activities are (at the optimal level of System Engineering effort) 85% of the total effort in a program. As can be seen, most of the R&D efforts is after the early phases (mission, needs, requirements, architecture) with a decreasing role for the Systems Engineering activities.

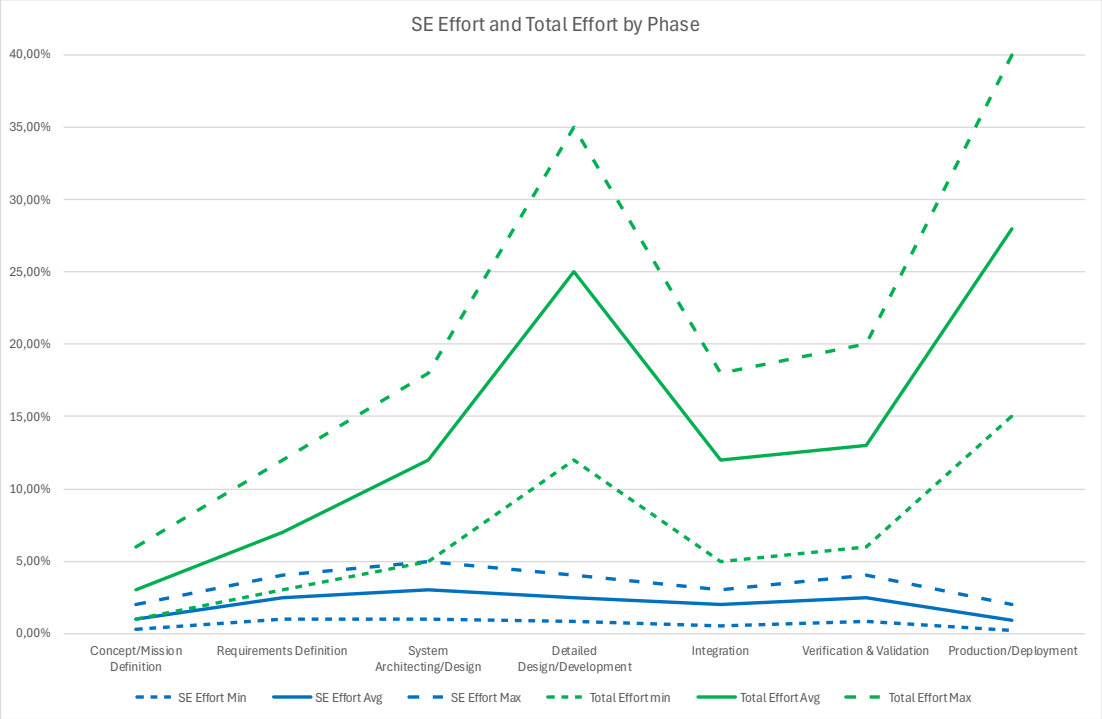


Figure 3: Systems Engineering effort and Total Effort by life cycle phase based on [43]

Generally, this is explained by the cost of rework by phase for Systems Engineering and Software Engineering, which increases exponentially for systems and for traditionally developed software (see Table 1 based on data from [47]).

Table 1: Cost of resolving defects by phase

Phase	Systems Engineering	Software Engineering
Requirements	1x	1x
Design	3-8x	5-7x
Build	7-16x	10-26x
Integration & Test	21-78x	50-177x
Ops	29-1500x	100-1000x

Others provide lower ranges for systems engineering [48] and traditional software development [49] [50]. Agile proponents argue that the cost of change curve in agile is significantly lower due to the frequent releases to production resulting in much shorter development cycles [51] [52] [53]. However, at the same time the agile approach to quickly deploy to production has resulted in several very high-profile outages [54] [55] [56] [57] [58].

2.8 Model-Based Systems Engineering

Model-based systems engineering is included in this review because it represents the most actively debated extension of systems engineering practice, and because its productivity benefits remain contested in ways that are directly relevant to this report's questions about R&D productivity measurement. INCOSE introduced Model-Based Systems Engineering

(MBSE) in their Systems Engineering Vision 2020 [59] in September 2007. [59] defines Model-Based Systems Engineering as “The formalized application of modelling to support system requirements, design, analysis, verification, and validation activities beginning in the concept stage and continuing throughout development and later life cycle stages”. Digital engineering extends the use of integrated models as authoritative source of truth to other disciplines [30].

MBSE is contrasted with a document-based approach to systems engineering. The INCOSE Vision 2025 from 2014 [60] mentions model-based systems engineering as a current practice. [61] in 2016 attributes the benefits of MBSE to increased development efficiency and defect prevention strategies through improved requirements completeness, consistency and communication.

[62] state though MBSE is seeing a fair amount of use, specific advances are needed to realize its full benefits. The 2019 state-of-the-practice survey [63] indicates perceived benefits in quality and efficiency, but also areas that prevent an effective introduction of a model-based approach. [64] discusses MBSE benefits have not been proven and the topic of demonstrating benefits and costs of MBSE should be a priority. [65] conclude that “there is no empirical evidence present in the publicly available literature today that supports the hypothesis that MBSE is beneficial for the development of engineered systems” based on papers across multiple industries. [66] concludes that there is insufficient empirical proof and proposes a framework to develop appropriate metrics. In 2025, [67] still indicate that MBSE offers many perceived advantages, but its adoption is hindered by amongst others uncertain ROI for the manufacturing domain.

The value of MBSE and its extension to Digital Engineering for R&D productivity thus is apparently not proven: do the perceived benefits outweigh the challenges and additional investments? This is consistent with the MBSE study phase 2 report [68], where estimating and prioritising the value of MBSE deployment was one of the key discussion points and the quantifying the value and success and of MBSE initiatives an important theme in the next steps.

3 State of the Practice

This chapter describes the second source of information for this project, viz., semi-structured interviews about the state-of-the-practice with representatives from the Dutch high-tech equipment industry (ASML, Canon, Philips, Thales, and Vanderlande). The general impression is that though all companies ask for productivity improvements, each company has its own specific needs and approaches. The following subsections cover the main topics that were raised and that feed into our project contributions in later chapters.

3.1 Measuring R&D Productivity

As the interviews reveal, R&D productivity is understood differently across organisations and roles, frequently characterised as achieving more output with the same resources or enhancing the value delivered for each euro invested. While productivity tends to focus on efficiency and output, quality is typically regarded as a distinct measure. A common thread across all interviewed organisations is that no single, universal, or standardised metric captures R&D productivity, and the challenge surfaces at three levels: in the day-to-day work itself, in the scope of what counts as R&D, and in the assessment of R&D improvement projects. Cross-cutting themes such as waste, AI adoption, change management, and domain knowledge are addressed in their own sections later in this chapter.

At the day to day level, it was mentioned organisations rely on a combination of surveys, key performance indicators (e.g., absolute metrics like lines of code, epics, patent portfolio, market position, etc.), and approximations (e.g., relative metrics like reality in comparison to planning/estimation or previous activities done). Although market share is a widely recognised long-term objective, it is considered a lagging indicator and may not fully capture the immediate effectiveness of R&D efforts. Organisations also grapple with balancing quality and speed, often prioritizing effectiveness (doing the right things) over velocity, or simply doing things right.

At the scoping level, in multiple interviews, it was mentioned that the tension between platform-based solutions and bespoke products often shapes the scope of the engineering activities. While platforms promise scalability, reuse, and long-term efficiency, bespoke products cater to highly specific customer needs, driving differentiation but increasing complexity. As a result of this duality, frequently the R&D is pulled towards engineering, as teams adapt platform architectures to unique requirements or customize solutions for niche applications. Additionally, the scope of R&D differs between organisations, for example, whether custom solutions are considered part of R&D or part of the market organisation. This boundary question complicates measurement before any metric is chosen, because it affects what gets counted as R&D in the first place. At the level of R&D improvement projects specifically, measurement is harder still. Unlike easily quantifiable manufacturing outputs, R&D involves complex, long-term projects and varied domains, making it difficult to apply uniform measurement methods. As a result, organisations often rely on qualitative assessments and rough estimates, which do not provide the accuracy or consistency needed for confident investment decisions. This challenge is the starting point for the waste-reduction reasoning developed in Chapter 5.

In response, organisations are increasingly inclined to prioritise pragmatic, outcome-oriented approaches over exhaustive metric development. There is a preference for “black box” productivity gains (i.e., accepting improvements that are observable, even if not fully

attributable) rather than expending disproportionate effort on precise measurement. At the same time, there is a recognition that a limited number of well-adopted tools may deliver greater value than a proliferation of underused solutions.

3.2 Business Case for Investments in AI

Investing in AI to boost R&D productivity is challenging for technology organisations according to our interviews. The imperative to demonstrate a positive business case for AI investments is mentioned as a recurring theme. Senior management and stakeholders demand clear evidence that AI-driven initiatives yield tangible benefits.

Although AI promises greater efficiency and innovation, assessing its return on investment (ROI) remains difficult and the ROI often remains unclear. Recall from Chapter 2 that also our literature review indicated no simple relation from the use of AI and GenAI to productivity. Attributing productivity improvements to particular AI tools or interventions remains inherently ambiguous. Many improvements are context-dependent, and the effects of AI may only become apparent over extended time horizons. This challenge is compounded by the fact that market share (as the ultimate indicator of value creation) is a lagging metric, often reflecting the cumulative effect of numerous factors beyond AI adoption.

Another layer of complexity mentioned in the interviews arises from the scope of AI applications. In R&D, activities such as software coding constitute only a fraction (though increasing) of total effort. Consequently, AI tools focused narrowly on coding automation address only a limited segment of the productivity equation. Broader organisational processes, including verification and validation, regulatory compliance, and cross-domain collaboration, must also be considered when evaluating the potential impact of AI.

Perhaps the most significant barrier seen to realise the benefits of AI investments is organisational change management (mentioned during the interview: “AI is 80% change management”). The successful deployment of AI requires not only technical integration but also widespread adoption and behavioural change across the workforce. Resistance to new tools, fragmented adoption, and underutilization can all undermine the anticipated returns on investment.

3.3 Company Culture

The culture of an organisation plays a pivotal role in shaping the productivity of its R&D function. Across the interviews, several cultural dimensions emerge as critical determinants of both the effectiveness and efficiency of R&D activities.

Different organisations display contrasting attitudes towards measuring productivity and value. Some adopt a culture that prioritises tangible outcomes and consistently seek to justify investments (especially in AI) using clear business cases and measurable results. This leads to an ongoing effort to identify objective metrics, even though the complex nature of R&D makes precise measurements challenging. Others take a more opportunistic approach, focusing less on strict cost reduction and more on capitalising on business opportunities and ensuring profitability, rather than relying on detailed productivity metrics.

A key insight is that implementing technological change, particularly the integration of AI and new digital tools, presents significant cultural challenges. The process of adopting tools that enhance productivity relies not just on their technical strengths but also on the organisation’s readiness to embrace new working approaches. Common obstacles to achieving the full

benefits of R&D investments include resistance to change, inconsistent adoption of tools, and underutilisation of available tools.

A next insight relates to whether knowledge workers are seen as assets to develop or as costs to minimize. Valuing talent leads to learning, autonomy, and innovation, while treating employees as expenses prioritizes short-term gains and rigid metrics, limiting creativity and engagement (especially in engineering). Balancing investment in people with efficiency is crucial for ongoing productivity and innovation.

Company culture significantly impacts how organisations learn from both internal and external sources. Interviewees point out that repeatedly solving the same problems is inefficient and stress the need for broader cross-domain learning and collaboration. Cultivating a culture of openness, sharing knowledge, and adopting best practices across teams and with partners is regarded as vital for boosting productivity and preventing unnecessary duplication of effort.

Creating the right balance between strict adherence to processes and maintaining flexibility is a key cultural factor influencing R&D productivity. Excessive focus on processes and performance metrics can distract from meaningful results and restrict innovation, while too little process discipline may lead to inefficiencies, duplicated efforts, and unclear responsibilities. The most successful organisational cultures are those that ensure processes facilitate, rather than impede, the attainment of R&D goals.

Employee satisfaction and engagement are increasingly recognised as crucial cultural factors driving productivity, as also showed up in our literature review from Chapter 2. For instance, actively tracking employee satisfaction and resolving obstacles to execution can help pinpoint important areas in need of enhancement. Cultures that empower engineers, minimise unnecessary administrative tasks, and foster a sense of purpose are more likely to achieve sustained gains in productivity.

Aligning incentives with strategic objectives is a cultural matter that directly affects R&D productivity. Conflicts between sales-focused rewards and engineering aims, or short- versus long-term priorities, can hinder progress. Thus, it is seen as important to ensure cultural norms and reward systems support the intended behaviours and results.

3.4 Lack of Domain Knowledge

A key concern highlighted in our interviews regarding R&D productivity is the lack of sufficient domain knowledge within engineering teams. This may be related to the challenges around tacit knowledge that showed up in our literature review from Chapter 2. This challenge has significant implications affecting both the efficiency and quality of product development activities, and would benefit from systems engineering practices like defect prevention through early verification and validation.

Multiple manifestations of the lack of domain knowledge were mentioned during the interviews. Engineers lacking domain knowledge often compensate by generating an excessive number of formal requirements to address uncertainty. This fails to address the underlying knowledge gap and can actively hinder progress, because the resulting volume of requirements makes it harder to locate the crucial information needed for effective decision-making. As teams expand and become more diverse, reduced communication and limited domain knowledge can lead to misinterpretation of requirements, misunderstandings, and ineffective solutions, especially in the absence of experienced experts. Additionally, when engineers concentrate too much on detailed tasks and performance indicators, they risk losing sight of broader objectives and

overall system requirements. The result is greater inefficiency, delays, and products that may not meet intended objectives, with excessive reliance on formal requirements worsening the issue.

The primary root causes mentioned were two-fold. Firstly, rapid organisational expansion and the addition of new personnel have resulted in teams with less collective experience. New employees often lack adequate exposure to the relevant domain, making it challenging for them to contribute effectively without significant training and guidance.

Secondly, there is a tendency for teams to prioritize proficiency with tools (such as AI and MBSE) without first developing a solid understanding of the underlying engineering or system context. This overreliance on tools can detract from the essential need for comprehensive domain knowledge, as tools are intended to support, not replace, fundamental engineering knowledge.

3.5 Time to Gather Information

A key issue impacting R&D productivity that was mentioned in our interviews is the perception that information gathering an engineering decision takes too much time. The activity itself is not viewed as wasteful. Gathering relevant contextual data, clarifying objectives and requirements, comparing against industry standards, and ensuring alignment with both internal and external expectations are all necessary preparatory steps, and skipping them can produce expensive late-phase corrections. The concern raised in the interviews is that the preparatory phase consumes disproportionately more time than it should, which makes it a primary candidate for productivity improvement rather than an activity to be eliminated.

Inefficiencies in the information-gathering phase of R&D can adversely affect productivity in several ways. Prolonged periods dedicated to collecting necessary data can lead to delays in making important design and development decisions, which in turn hampers the pace of innovation. Additionally, highly skilled team members may find themselves spending excessive amounts of time on tasks that do not directly add value, such as searching for relevant information or clarifying requirements, rather than focusing on their core technical or creative responsibilities. Furthermore, when the required information is incomplete or not readily accessible, decisions may be made without sufficient context, thereby increasing the risk of suboptimal outcomes and potentially undermining the quality and effectiveness of R&D efforts.

To address these inefficiencies, it is mentioned that organisations could optimise their handling of information across stakeholders, governance, and processes. This includes ensuring timely and comprehensive access to relevant information, establishing clear expectations and decision criteria at the outset, streamlining communication channels among stakeholders, and critically assessing the documentation practices, particularly those that may offer limited value in early project stages. According to the interviews, adopting these measures can significantly reduce delays and improve overall productivity within R&D teams.

3.6 Integrated Toolbox for Engineers

An integrated toolbox for engineers is mentioned in our interviews as a strategic necessity within the Dutch high-tech equipment industry. It refers to an interoperable collection of engineering tools and platforms (e.g., computer-aided design systems, simulation environments, data management solutions, and AI assistants) that are closely connected to support the full engineering process, from the initial design and analysis stages through to documentation, manufacturing, and lifecycle management.

In our interviews, several essential characteristics were mentioned for a comprehensive and truly integrated toolbox for engineers:

- Interoperability across the constituent tools, enabling frictionless exchange of data between different platforms.
- Scalability, capable of supporting growing complexity and facilitating multidisciplinary engineering efforts as well as large-scale projects.
- Automation of routine and repetitive tasks (such as documentation checks and tolerance analysis) using AI and advanced analytics, to reduce manual effort.
- A user-centric design that ensures intuitiveness, so that engineers can focus their attention on creative and complex problem-solving rather than being occupied by administrative tasks.

The interviewees suggested that an integrated toolbox of this kind would significantly enhance organisational productivity by streamlining operations and reducing inefficiencies. By minimising manual work and eliminating non-value-adding tasks, engineers can dedicate more attention to innovation and effective problem-solving. Integrated platforms also foster knowledge sharing, allowing best practices, insights, and specialist expertise to be more readily disseminated among teams. To remain effective in the face of changing engineering demands, the toolbox must also be regularly updated to incorporate advancements in technology and methodology.

While the advantages of integration are evident, realising this objective is often challenging. Many organisations face difficulties due to fragmented tool ecosystems, outdated legacy systems, and resistance to change. The lack of an interoperable engineering platform (comparable to integrated business suites) serves as a major obstacle. Addressing these issues necessitates effective change management, the establishment of standards, and sustained investment in the development of tools.

4 Business Strategy

This chapter describes the first reasoning line that we have developed, viz., a framework that explains the influence of business strategy on the interpretation of the “productivity” concept. The following subsections explain the various aspects of this framework.

4.1 Why the Output/Input Formula Breaks Down in R&D

We began not by proposing a new metric, but by asking why the existing ones fail in R&D settings. The desk research and interviews made it clear that measurement will continue to break down until we can first describe what kind of work is being done and what kind of progress it is supposed to create. Only then can the familiar productivity formula regain its meaning. Any serious attempt to measure R&D productivity must start with a framework that clarifies intent and context before it attempts to quantify output.

The enduring appeal of the output-over-input formula lies in its elegant clarity: it promises a universal way to reason about productivity by connecting what an organisation invests to what it receives in return. This framing works particularly well in domains such as manufacturing, logistics, and operations, where outputs are standardized, repeatable, and comparable over time. In those environments, the transformation process is well understood, the variability of work is deliberately minimized, and the meaning of “output” remains stable from one cycle to the next. When a process produces identical units according to a controlled workflow, the relationship between effort and result becomes transparent, allowing organisations to evaluate improvement with confidence. The formula is not only intuitive, it is operationally useful because it reflects a world in which value is tangible and incremental gains map directly to measurable changes in performance.

The formula’s universality also gives it managerial power. Leaders prefer metrics that can be communicated easily across teams, functions, and reporting structures, and the output/input ratio aligns naturally with financial logic, project accounting, and resource allocation models. Countless books and articles have attempted to help these leaders with formulas called acronyms like KPIs, OKRs, and V2Moms. It embodies the logic of return on investment without the complexity that often accompanies R&D [33]. In predictable environments, this simplicity is a feature. However, when applied to R&D, it becomes a fundamental flaw because it creates the dangerous illusion that productivity can be governed by a single conceptual tool [6]. While the equation serves as an effective mechanism for accountability and benchmarking as long as outputs are clear and stable, research demonstrates that attempting to collapse complex, multidimensional knowledge work into a single dimension consistently misrepresents the underlying concept [11].

4.1.1 Lack of Output Uniformity in R&D

The formula collapses in R&D because it assumes that outputs are coherent and comparable, when in reality they vary wildly in nature, purpose, and timescale. Unlike manual or assembly-line operations, where the repetitive task itself "programs the worker", R&D is nonroutine knowledge work where almost every task is fundamentally different from the last [6].

Consequently, R&D produces no single class of deliverable that can be counted or aggregated meaningfully across efforts. The same inputs, talent, time, tools, and budget, may generate a feasibility study, a conceptual prototype, a risk-reduction insight, a negative result that closes off an unproductive path, or an architectural decision that shapes future work. These outputs differ not only in form, but in their relationship to value creation. A single feasibility insight may be decisive for strategy, while a dozen prototypes may be inconsequential. The heterogeneity is structural, not incidental.

This diversity becomes even more pronounced because R&D outputs serve different purposes at different stages of maturity. Early exploratory work seeks to reduce uncertainty or expand the option space, creating "option value" that provides the organisation with the strategic flexibility to respond to future market or technological shifts. Later development work seeks refinement, predictability, and reliability. The same week of engineering effort may be “productive” in entirely different ways depending on whether its purpose is discovery, alignment, stabilization, or optimization. When organisations treat these forms of progress as if they were interchangeable, they distort both what productivity means and how it should be evaluated. they fall victim to the myth of "one metric that matters", inappropriately flattening complex, multidimensional work into a single score that strips away vital context [10]. The formula fails not because inputs change, but because the implicit assumption of output uniformity does not hold in knowledge-intensive environments.

The failure deepens when we consider that many R&D outputs are intangible, cumulative, or only partially observable. Architectural clarity, risk retirement, conceptual reframing, or the invalidation of a hypothesis rarely manifest as discrete deliverables, yet they profoundly influence later work. These contributions represent critical "invisible work" that drives overall team success but goes completely unmeasured by standard activity counts [9]. Traditional metrics cannot absorb these contributions, and the output/input formula leaves no room for them. As a result, teams producing crucial early-stage knowledge appear unproductive when judged through a lens designed for repeatable production.

4.1.2 Why Organisations Misapply the Formula

Organisations misapply the formula because each layer of the hierarchy substitutes its own mental model of “output”, creating a fragmented interpretation of productivity that appears coherent only on the surface. This fragmentation is not a failure of communication, but a structural reality: complex organisations frequently operate as "organised anarchies" driven by a variety of inconsistent, unreconciled, and ill-defined preferences rather than a single, shared goal [69]. Productivity research explicitly defines this fragmentation through different organisational "lenses" [10]. The organisation, or executives, often equate output with strategic progress, new market opportunities, competitive positioning, or the acceleration of long-term value creation [10]. Managers interpret output as project milestones, throughput, and predictable sequencing of work. Engineers understand output as the concrete, near-term artifacts that define daily progress: prototypes, design explorations, experiments, or performance improvements. All of these interpretations are rational within their own domain, but they are incompatible when forced into a single metric [5]. The formula, intended to unify, becomes a mechanism for misalignment because everyone believes they are discussing productivity, while in reality they are discussing different outputs, different time horizons, and different definitions of progress.

This fragmentation produces predictable pathologies. Throughput, stability, and change failure rates each illuminate different failure modes. Performance emerges only when these dimensions are interpreted together [70]. Exploratory teams get judged for a lack of feature

delivery. Optimization teams get criticized for a lack of novelty. Maintaining teams get pressured to innovate rather than stabilize. And adaptive teams get punished for taking the time to maintain or optimize their work, because those necessary stabilizing activities detract from the rapid market responsiveness they are expected to deliver. Across these examples the mismatch is categorical rather than numerical, which is why it persists regardless of how carefully the metric is tuned.

4.1.3 The Measurement Conundrum

These contradictions culminate in a measurement conundrum: productivity cannot be assessed when the central term of the equation, “output”, has no shared or stable definition. Without agreement on what constitutes meaningful progress, the formula becomes an empty shell. The conundrum is not resolved by refining the metric or adding additional KPIs, because the underlying issue is categorical. R&D contains multiple types of work that pursue fundamentally different forms of value. Without first distinguishing these types, no amount of quantitative refinement can produce a coherent measure of productivity. This is why organisations that rely heavily on output/input often find themselves debating not the numbers but the meaning behind them.

To resolve the issue, we need a framework that clarifies the nature of the work being performed before we attempt to evaluate its productivity. Only by establishing the context, what kind of progress is expected and why; can the formula regain its usefulness. This framework will need to provide the missing structure needed to make R&D productivity measurable in a meaningful way.

4.2 The Quadrant Model: A Framework for Understanding R&D Intent

Organisations have long struggled to classify R&D efforts in a way that enables meaningful measurement. To overcome the limitations of traditional classifications, the Quadrant Model introduces a more precise framework by synthesizing two established theoretical spectrums:

- the exploration-to-exploitation axis [69] and
- the market-pull-to-technology-push spectrum [71].

While both are well-known and extensively researched concepts individually, to the best of our knowledge, this is the first time they have been combined into a single, unified framework. By intersecting these two axes, the Quadrant Model provides a dynamic and comprehensive map of the innovation ecosystem, allowing organisations to categorize R&D intent accurately.

While academic literature traditionally uses the term "technology push" to describe the commercialization of a specific new technical capability or invention [72], applying this concept to an entire R&D portfolio requires a broader organisational perspective. At the enterprise scale, this dynamic is more accurately described as a "business push." This shift in terminology is supported by Van den Ende and Dolfsma, who emphasize in their historical analysis of computing technology that technological knowledge and market demand are merely contextual "enablers" of innovation; they cannot generate change in a vacuum because "actors are needed who create the innovations" based on that knowledge [73]. As Isoherranen and Kess note, this orientation is fundamentally driven by a company mobilizing its internal assets, skills, and core competencies to create a competitive advantage, rather than relying solely on isolated

technological breakthroughs [71]. Furthermore, Brem and Voigt expand on this internal drive by identifying that innovation impulses are frequently "corporate-interest-driven," meaning they are actively propelled by the overarching strategic and operational goals of top management [72]. By adopting the broader concept of a business push, the Quadrant Model scales the traditional technology-push axis to reflect how an organisation as a whole leverages its collective internal capabilities and strategic agenda to shape the market, rather than evaluating innovations one technology at a time.

4.2.1 The Traditional Spectrum, Research and Development

The familiar distinction between “research” and “development” fails to explain the diversity of R&D work because both terms carry inconsistent meanings across organisations, disciplines, and maturity levels. Some describe research as long-horizon scientific exploration, while others define it as early prototyping or feasibility investigation. Similarly, development is alternately interpreted as late-stage refinement near productization, iterative engineering after concept selection, or any work beyond initial discovery. These variations reflect local norms rather than universal categories, and they reveal that the research/development axis is too coarse to capture how teams actually behave. As a result, it does not help organisations to classify their efforts in a way that enables meaningful measurement or comparison.



Figure 4: The spectrum between Exploration and Exploitation

To correct this, Figure 4 illustrates how the traditional research-to-development axis can be more accurately reframed as a spectrum ranging from exploration to exploitation. The research/development axis also assumes that technical maturity alone determines the nature of the work, yet our observations show that teams at similar maturity levels may operate with different priorities, risk tolerances, and decision rhythms. One team with a technically mature concept may still behave in exploratory ways if the business case or market direction is unclear, while another team working on earlier-stage technology may behave like a delivery organisation if the customer need is fully defined. The research/development axis cannot account for these differences because it conflates technical readiness with intent, and intent is often the more decisive driver of how work is performed. Research on organisational learning shows a structural asymmetry between exploration and exploitation. Exploitation improves performance quickly and therefore receives disproportionate reinforcement. Exploration produces slower and more uncertain returns, yet without it, organisations drift toward short-term competence and long-term fragility [69].

4.2.2 Why a Second Dimension Is Needed: Technology Push vs Market Pull

A more complete understanding of R&D work requires a second dimension that distinguishes whether the effort originates from internal strategic drivers or external market signals. This distinction, often described in innovation theory as technology or business push versus market

pull [71], captures the motivation behind the work, not just its technical maturity. The character of a project changes dramatically depending on whether it is initiated to advance an internal strategic agenda or to respond to customer demand, competitive pressure, or environmental shifts.

Recent reviews of innovation research show that technological opportunity and market demand are not competing explanations but interdependent forces. Companies innovate by integrating both, and the companies' competence determines how effectively technology is matched to demand [72]. Historical analyses of computing technology show that demand does not merely select among existing technological trajectories; in several periods it actively enabled the emergence of new paradigms. For example, Research shows that the most successful modern innovations occur when companies leverage new digital capabilities like AI and IoT (technology push) specifically to meet the growing customer demand for highly personalized, flexible products (market pull) [75]. This contradicts the common assumption that only scientific advance can initiate a new technological direction [73].

The push/pull axis explains behaviours that the traditional, maturity-based research and development classifications cannot. Teams driven by a business strategy push tend to explore possibilities, extend technological capability, or improve internal systems, even when the external environment is relatively stable. In contrast, teams responding to external market pull prioritize responsiveness, speed, and alignment with emerging needs. These differences shape decision-making, sequencing, validation methods, and expectations about acceptable risk. Without the push/pull axis, organisations cannot differentiate between two teams working on the exact same technology. On paper, both projects may appear identical in technical maturity; in practice, a team frantically adapting that technology to match a competitor's sudden release operates with entirely different rhythms, risk postures, and decision criteria than a team deliberately refining that same technology to build a long-term internal capability. This second axis exposes these motivational patterns, clarifying why teams facing similar technical challenges may operate in fundamentally different ways.

4.2.3 How the Two Axes Create a Clearer Framework for R&D

When these two axes are combined, they create a clearer map of how R&D organisations actually function. The research/development axis (exploration–exploitation) captures how teams approach uncertainty and learning. The push/pull axis (internal-external focus) axis captures what motivates the work and where the direction-setting forces originate. Combining the two axes reveals four distinct modes of R&D behaviour, each defined by a different underlying theory of progress. Figure 5 presents this combined structure, plotting the cross-section between the exploration-exploitation continuum and the business-push/market-pull orientation.

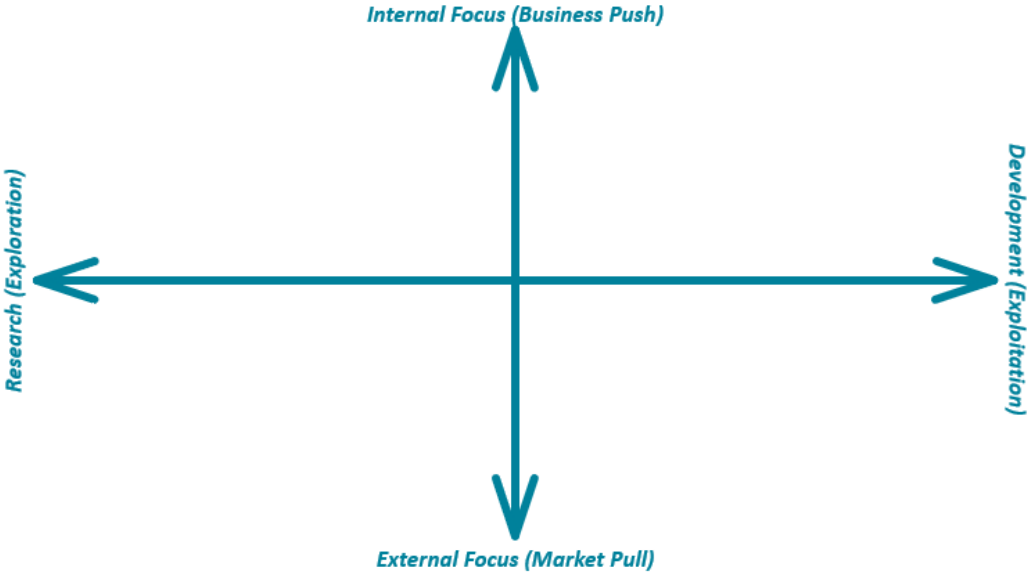


Figure 5: The cross section between exploration through exploitation and business push through market pull.

The Quadrant Model operates as a nested system, meaning these classifications scale across the entire hierarchy, from the macro-organisational level (executives setting portfolio strategy), down to the management level (coordinating initiatives), and finally to the producer level (individual engineers executing tasks).As March observes regarding the tension between exploration and exploitation, these same dynamics occur across "levels of a nested system, and at the individual level, the organisational level, and the social system level" [69]. Similarly, modern productivity frameworks emphasize the necessity of viewing work through distinct "lenses" (such as the organisation, the team, and the individual) because the context and goals of the work shift at each scale [71]. Therefore, while an entire enterprise might fit into a specific quadrant based on its overarching market strategy, the specific teams within that enterprise also distribute themselves across the four quadrants to execute that strategy. Recognizing this fractured nature is essential, because it exposes structural misalignment. For instance, if an organisation's overarching strategy requires it to act as an externally focused exploratory enterprise, but its individual teams are operating as internally focused development units, the organisation will fail to achieve its strategic goals. The danger here is that these misaligned teams may still be highly "productive" at creating high-quality deliverables [12]. However, because they are operating with an intent that is disconnected from the overarching strategy, they are efficiently producing the wrong things for the wrong reasons [12]. This disconnect is notoriously difficult to diagnose without a multi-level framework, as local team success on paper can actively mask strategic failure at the organisational level.

With both axes in place, the matrix resolves four behavioural patterns that recur across R&D organisations but are usually conflated under a single notion of "delivery." Teams pursuing new technological possibilities under internal scientific or architectural drivers occupy the disruptive quadrant, exploring the boundaries of what is technically feasible. Teams responding to shifts in markets, customers, or competitive moves operate in the adaptive quadrant, exploring which paths remain viable as external conditions change. Teams refining established products for existing customers work in the maintaining quadrant, exploiting current capability to protect

competitive position. Teams improving mature systems to reduce internal friction function in the optimization quadrant, exploiting existing architectures to remove accumulated inefficiency. Section 4.3 develops the strategic logic and productivity implications of each quadrant in detail.

4.2.4 Why the Quadrant Model Reflects How R&D Actually Operates

Large R&D organisations naturally distribute their efforts across all four quadrants because they must balance exploration and exploitation while also navigating internal priorities and external demands. For example, an analysis of the mobile phone industry illustrates this lifecycle progression: companies often establish market dominance through a ‘technology push’ focused on internal R&D capabilities (internal priorities), but must transition toward ‘market pull’ strategies to address specific customer values (external demands) to sustain that position as the product matures [71] [73]. They investigate breakthrough technologies while stabilizing existing offerings; they respond to emergent customer needs while removing inefficiencies from legacy platforms. When viewed through the quadrant model, this landscape becomes intelligible rather than chaotic. The model shows that such diversity is not a flaw but a functional necessity for long-term competitiveness.

What becomes important is not the presence of work in each quadrant, but the distribution of work across them. This distribution reflects how the organisation invests its time, talent, and resources, revealing its implicit strategic posture. A portfolio weighted heavily toward disruptive and adaptive work signals an exploratory stance, while one weighted toward maintaining and optimization work signals a focus on consolidation and operational strength. While individual projects are inherently dynamic, often migrating from an exploratory quadrant into an exploitative one as they mature and scale, the overarching distribution of the portfolio provides a stable, macro-level indicator of the organisation's true strategic intent.

The model therefore provides a dynamic map of the organisation’s innovation ecosystem. This mapping is essential for exercising what strategic management research calls "dynamic capabilities" [71]. An organisation's dynamic capabilities refer to its agility to change strategy drivers, reconfigure resources, and shift efforts between exploratory and exploitative modes as the environment demands [71]. Organisations survive structural change not by picking a single winning quadrant, but by possessing the dynamic capability to navigate these transitions across the portfolio. This capacity, rather than any single static configuration, predicts long-term adaptability, renewal, and survival, and the capacity to navigate these transitions, rather than any single configuration, predicts long-term adaptability [71] [74].

4.2.5 The Concept of the Centre of Gravity

The notion of a shifting centre of gravity allows us to understand R&D portfolios not as static sets of initiatives but as an evolving distribution of effort across the four quadrants. In this report, the centre of gravity refers to the weighted concentration of projects and resources within the quadrant model, where larger or more resource-intensive initiatives exert greater influence on the portfolio’s overall position. It is therefore a portfolio-level concept that emerges bottom up from the distribution of individual projects.

Figure 6 illustrates this view. Each solid circle represents an initiative, sized by the effort invested in it. The dashed boundary represents the organisation's area of influence, meaning the span of quadrants in which the organisation actively operates. The centre of gravity sits within this area and identifies where the bulk of effort is concentrated, while the area itself

indicates how broadly the organisation plays. Two organisations with identical centres of gravity can therefore have very different areas of influence, with material consequences for resilience and adaptability.
Over time, individual projects migrate across quadrants as their dominant intent evolves. A project may begin in disruptive exploration, shift into adaptive work as external signals become clearer, mature into maintaining work focused on reliability, and eventually transition into optimization aimed at cost and complexity reduction. As projects move and as the relative effort invested in them changes, the portfolio's centre of gravity shifts accordingly.

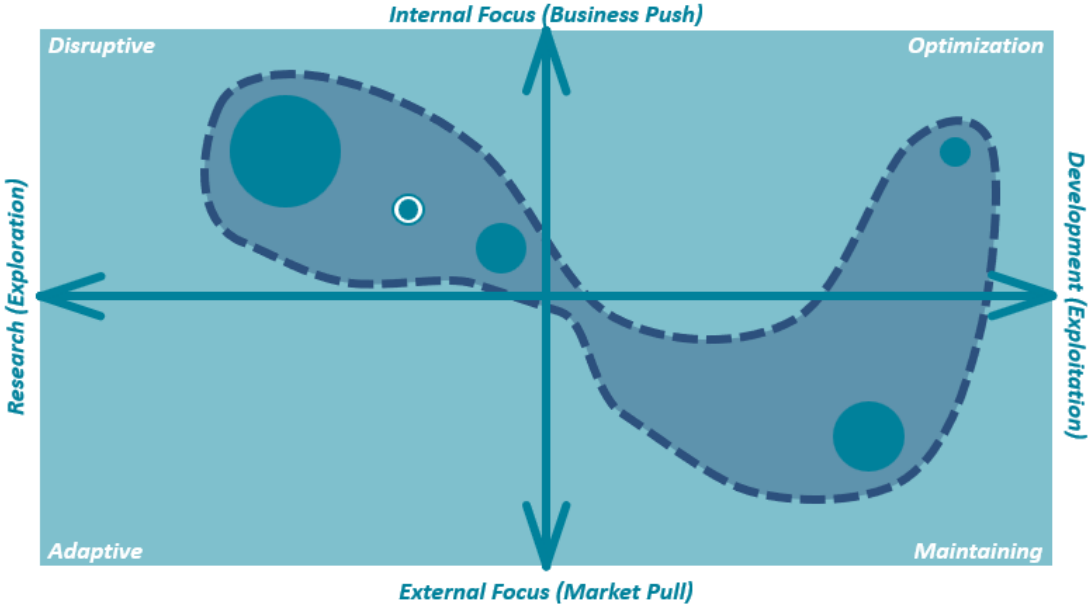


Figure 6: An example of projects within an R&D organization. The solid circles represent initiatives or projects where the size is the effort invested, and the dashed area represents the organizations area of influence.

The centre of gravity can also shift abruptly. Regulatory changes, new competitors, economic disruptions, or technology breakthroughs redirect projects, funding, and managerial attention toward different quadrants, and the weighted distribution of effort moves with them. These shifts are not trivial, because each quadrant demands a different operating posture. A sudden pull toward adaptive work requires speed and responsiveness. A shift toward maintaining requires discipline and predictability. A shift toward optimization requires rigour and efficiency. Without recognising these changes, organisations risk applying outdated expectations to work whose strategic intent has already changed.

4.2.6 Why This Framework Is Necessary for Understanding Productivity

The quadrant model is essential because productivity cannot be meaningfully assessed until we understand which quadrant a team is operating in and why. Modern software engineering research provides extensive evidence that productivity is "highly task and situation dependent" and that attempting to flatten complex knowledge work into a single, context-free metric consistently misrepresents the underlying effort [12]. Because productivity is so heavily influenced by the context in which the work is done, any measurement must begin by defining the specific goals of the task [11].

Each quadrant represents a different conception of progress: creating possibilities (Disruptive), generating insights (Adaptive), increasing reliability (Maintaining), or removing friction (Optimization). These forms of progress are not interchangeable, and they cannot be evaluated using the same expectations or metrics. By identifying the strategic intent behind the work, the model resolves the ambiguity that undermines traditional productivity measures. Both the technology push and market pull streams of innovation research converge on one conclusion: innovation intent is fundamentally context-dependent. In some periods, technological knowledge is the dominant enabling force, in others changing market conditions lead. Classifying work without considering this context obscures which logic is actually driving behaviour [73].

4.3 Strategic Focus Areas for each Quadrant

The primary contribution of the quadrant model is that it reveals the underlying purpose of the work being performed. Each quadrant operates under a distinct logic of progress: some efforts aim to push the technological frontier, others to respond quickly to external signals, stabilise existing products, or remove friction from mature systems. Figure 7 summarises the strategic focus and example goals associated with each quadrant. Organisational ambidexterity research confirms that organisations routinely operate in multiple modes at once. Exploration and exploitation follow different logics, rely on different structures, and generate different forms of value. Treating them as a single category collapses distinctions that materially affect performance [75].

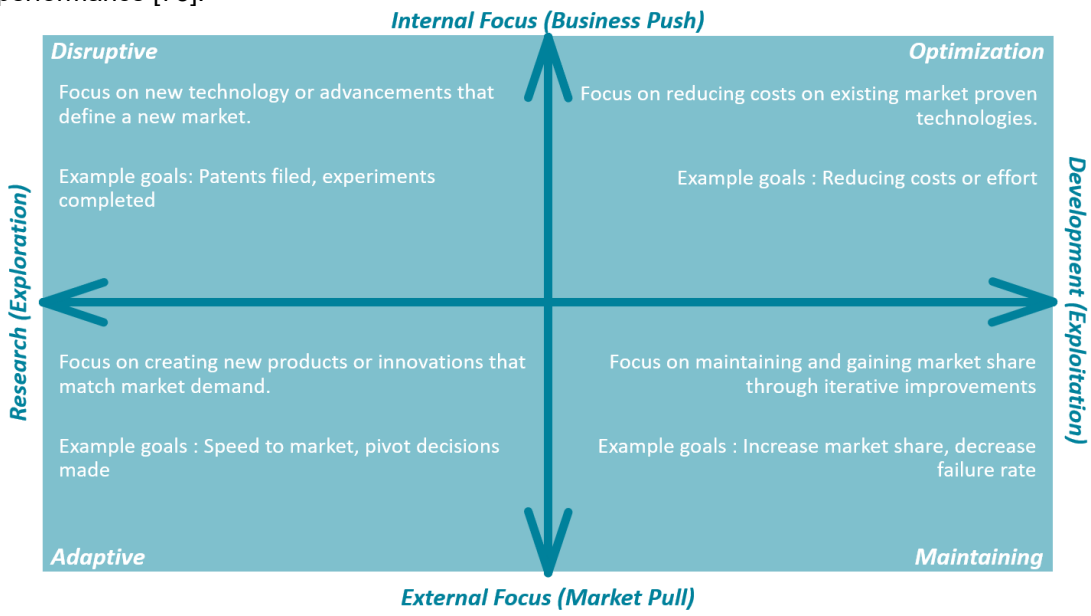


Figure 7: Focuses and goals per quadrant

The **disruptive quadrant** concentrates on work that seeks to create new technological options, new architectural concepts, or new scientific understanding. These efforts are not driven by immediate external demand. They are driven by the recognition that long-term competitiveness requires exploration beyond the boundaries of current capability. The strategic focus here involves learning at a deep level and reducing uncertainty that would otherwise prevent future development. Productivity in this context cannot be interpreted through the lens of feature delivery or near-term results. The relevant question is whether the organisation is broadening its option space and generating insights that will support future bets.

The **adaptive quadrant** reflects situations in which teams explore because the environment is shifting. The strategic intent is not to discover what is possible, but to understand what is necessary. Market changes, customer feedback, competitive moves, and regulatory developments create uncertainty about direction. The aim is to shorten the cycle between an external signal and the team's response by generating insights that clarify which paths are viable. The output that matters here is not stable throughput or feature volume, but the speed at which teams learn, test, revise, and realign.

The **maintaining quadrant** addresses work that is tied to products with established customers and established expectations. The strategic intent is to ensure continuity, reduce customer friction, and protect or strengthen the organisation's current competitive position. This work rewards discipline, predictability, and careful control of variation. Productivity here depends on the ability to deliver consistent improvements that reinforce trust and reduce operational or technical risk. These efforts are often undervalued in organisations that prize novelty. However, they represent a significant portion of the value created by mature R&D portfolios.

The **optimization quadrant** targets improvements to systems, tools, workflows, and architectures that have reached a stable state. The strategic intent is to remove inefficiencies that accumulate over time and to reduce the friction that slows engineering work. These improvements may not be visible to customers, but they have significant effects on long-term productivity, maintainability, and organisational agility. The relevant outputs in this quadrant are internal-efficiency gains such as reduced rework, faster integration, lower maintenance effort, or simpler architectures. These gains are often overshadowed by more visible work, yet they create the foundation on which all other quadrants depend.

Empirical work on strategy orientation shows that technology-push and market-pull organisations develop different decision rhythms, different tolerances for uncertainty, and different interpretations of progress. These orientations shape not only what teams deliver but how they reason about success [71].

4.4 Translating Strategic Intent Through the Organisation

Confusion about productivity often emerges not from poor performance but from inconsistent expectations across the organisational hierarchy. Research indicates that different stakeholders, such as developers, managers, and vice presidents, hold varied goals and interpretations of productivity, creating tension between individual, team, and organisational perspectives [10]. The same conflict appears horizontally across roles, where executives, managers, and developers evaluate the same work through different lenses, and individual, team, and market goals end up actively in tension [19]. If executives emphasize exploration while managers retain processes built for predictability, the work becomes constrained by structures that contradict its purpose. For instance, siloed functions often report notable operational improvements while overall customer satisfaction remains stagnant because local metrics fail to capture the end-to-end journey [76]. If managers attempt to encourage rapid iteration while engineers are evaluated on stability, teams receive mixed signals about what good performance looks like. Indeed, if a team is rated solely on metrics like story points, members may focus on optimizing their own points to the detriment of completing invisible work necessary for the broader system [9]. In these situations, productivity degrades because the layers of the organisation pull against one another. The work may be competent, but the

interpretation of that work is fractured, creating the appearance of inefficiency where none exists.

Although executives define the organisation's strategic posture and the role each quadrant should play within the portfolio, intent does not guide behaviour unless it becomes translated into expectations that managers and engineers can act upon. R&D organisations contain multiple layers of interpretation, and each layer views the work through a different lens (Figure 8):

- The executive layer thinks in terms of long-term direction and portfolio positioning.
- The management layer thinks in terms of coordination, cadence, and operational flow.
- The production layer thinks in terms of tasks, obstacles, and tangible deliverables.

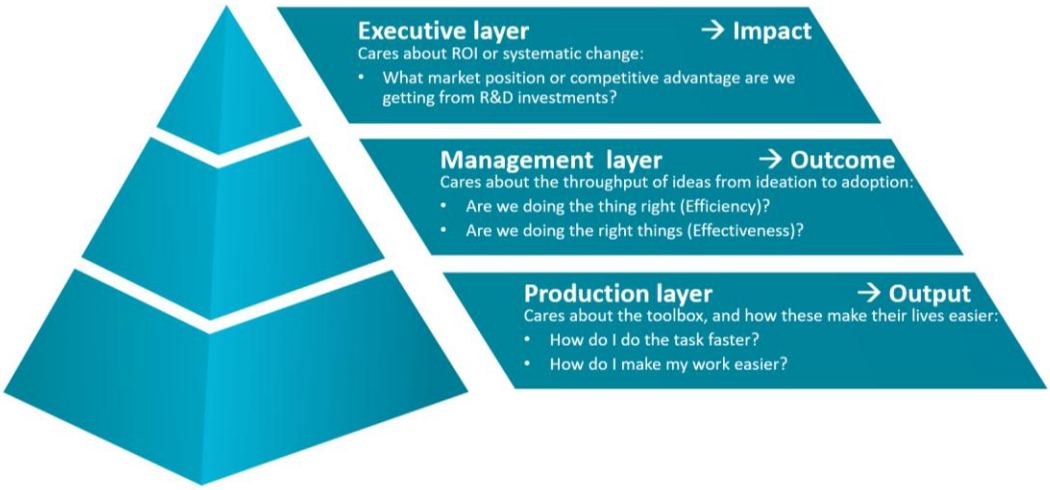


Figure 8: The translation pyramid. Executives, managers, and producers each interpret R&D work through a different lens, generating different categories of accountability (impact, outcome, output) at each layer. The questions shown are illustrative of generic layer concerns; per-quadrant translation is described in the text and summarised in Figure 9.

Without a structured mechanism that connects these perspectives, the same strategic intent produces different meanings at different levels. Productivity then becomes a contested concept rather than a shared objective.

Executives translate strategic intent into signals about desired impact.

The role of executives is to articulate what success should mean for the organisation at a strategic level. This articulation takes the form of impact-level metrics that indicate whether the chosen focus area is advancing. A disruptive initiative might be judged by the rate at which uncertainty is reduced. A disruptive initiative might be judged by the rate at which uncertainty is reduced. An adaptive initiative might be judged by the pace of validated learning. A maintaining initiative might be judged by reliability and customer stability. An optimization initiative might be judged by reductions in internal complexity or cost. For example, a maintaining initiative might focus on gaining market share by creating a new feature, and their metric would include the market share as in “Market Share per Euro spent.” These impact-level metrics do not specify how the work should be carried out. Instead, they provide direction that helps managers shape the operational environment.

Managers convert impact expectations into operational outcomes.

Managers operate at the level where strategy becomes action. Taking the impact-level metrics set by executives as their starting point, their responsibility is to shape workflows, review structures, and sequencing so that the organisation can generate the outcomes those metrics require. For disruptive work, managers prioritize mechanisms that encourage exploration, feasibility probes, and rapid insight generation. For adaptive work, they focus on iteration cadence, feedback loops, and fast decision cycles. For maintaining work, they emphasize predictability, disciplined integration, and quality gates. For optimization work, they concentrate on reducing variation, eliminating wasteful steps, and improving throughput. These outcomes serve as the bridge between strategic intent and concrete work.

Producers translate desired outcomes into practical outputs.

Producers translate desired outcomes into practical outputs, and the form of those outputs shifts with the quadrant. For disruptive work, engineers test bold ideas without requiring full business justification, learning through experimentation and producing feasibility evidence rather than finished features. For adaptive work, they repurpose existing market solutions to accelerate delivery, working from real customer or competitor signals rather than fixed specifications. For maintaining work, they follow stable, well-defined processes and use mature tooling to make changes safely, prioritising release reliability. For optimization work, they automate repetitive tasks and streamline workflows to remove rework and waiting from the system. These outputs are the manifestation of the outcomes defined by managers and the impact expectations set by executives. Producers interpret productivity through the immediacy of their work environment. They ask that tasks are well defined, obstacles are removed, and the conditions exist for meaningful progress. The clarity of this environment determines whether strategic intent can be realized at the level where value is actually produced.

Each quadrant requires a distinct posture toward risk, and these posture requirements must be understood across all levels. Disruptive work requires tolerance for ambiguity and the acceptance that many explorations will not lead to immediate results; returns from such exploration are systematically less certain, more remote in time, and organisationally more distant than returns from exploitation [69]. Adaptive work requires comfort with rapid decisions and incomplete information because responsiveness matters more than perfect accuracy. Maintaining work requires low tolerance for deviation because reliability is essential to customer trust. Optimization work requires the identification and removal of variation because efficiency depends on disciplined control. If executives communicate one risk posture but managers and engineers follow another, the organisation becomes structurally misaligned.

When executives define impact clearly, when managers operationalize that intent through coherent outcomes, and when engineers produce outputs that reflect those outcomes, the organisation begins to behave as a coordinated system. Productivity becomes a shared concept rather than a fractured set of interpretations. At this stage, the organisation is finally in a position to revisit the familiar productivity formula. Output can now be understood in relation to strategic intent, operational outcomes, and the concrete work produced by teams.

4.5 Reframing R&D Output

With each quadrant's intent established (Section 4.3) and the translation logic that carries that intent to the producer layer laid out (Section 4.4), output can

be redefined in a way that aligns with strategic intent rather than against a generic delivery standard.

Once output is defined relative to quadrant intent, the productivity formula, introduced in Section 4.1, becomes meaningful again at the level of the team or initiative. The equation no longer assumes that all forms of R&D work produce the same kind of result. Instead, it asks whether a team produced the form of progress appropriate to its intent, given the resources it consumed. A disruptive team is productive when it reduces uncertainty and expands the future design space, even if it delivers few concrete features. An optimization team is productive when it reduces cost and complexity, even if it produces no novel concepts. The structure of the formula remains the same, but the meaning of output becomes context dependent.

This reframing does not mean that productivity numbers from different teams can simply be added together to produce a meaningful organisational productivity score. That would reintroduce the same apples-to-oranges comparison at a higher level of aggregation. Instead, the portfolio must be interpreted through its distribution of work across the quadrants and its centre of gravity. Team-level productivity can then be assessed within the context of the strategic role each part of the portfolio is meant to play. At the organisational level, the key question is not whether all teams produce the same kind of output, but whether each part of the portfolio is producing the right form of progress for its strategic intent, and whether the overall distribution of effort is moving the organisation in the desired direction. In this sense, the quadrant model does not solve R&D productivity by inventing a universal metric. It solves a prior problem by making productivity interpretable, which is the precondition for the portfolio-level reasoning that the playbook in Section 4.6 operationalises.

4.6 Quadrant Playbook

The Quadrant Playbook is intended for R&D executive and manager levels in the organisation (e.g., executive, portfolio managers, program leads, and engineering managers). The quadrant model is not only a classification taxonomy. It is a decision-support framework for steering R&D portfolios under changing conditions, and the playbook operationalises it. It gives leaders a procedure to map their portfolio, locate its centre of gravity, and decide whether the current distribution of work matches the organisation's strategy. This is not only a vertical problem between hierarchy levels.

The playbook builds on the two axes introduced in this chapter (exploration versus exploitation, and business push versus market pull) and on the layered translation logic from Section 4.4 (executive intent into managerial outcomes into engineering outputs). It also assumes a portfolio perspective, recognizing that it extends beyond individual teams to reflect the organisation’s overall strategy and resource allocation.

The following six steps map the portfolio of R&D projects and initiatives, locate the centre of gravity, and translate the resulting diagnosis into action.

Step 1: Setting the scene

Provide an overview of the quadrant model by detailing the two axes (exploration versus exploitation, business push versus market pull) and clarify the strategic logic and type of progress associated with each quadrant. Figure 9 summarises the quadrant model populated with per-layer guidance and serves as the reference artefact for the mapping work that follows. The goal of this step is to create a shared understanding of the categories before any mapping begins.

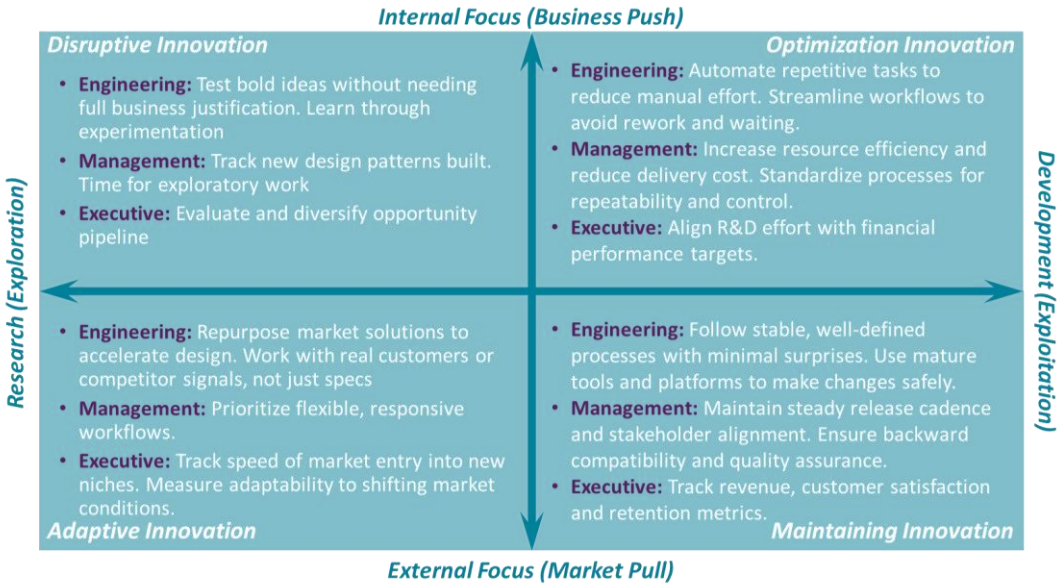


Figure 9: The quadrant matrix populated with per-layer guidance. Each quadrant carries a distinct logic of progress (exploration versus exploitation, business push versus market pull), and within each quadrant the executive, management, and producer layers ask different questions and pursue different forms of value. The matrix integrates the quadrant model from Section 4.3 with the translation pyramid from Section 4.4, and serves as the reference artefact for the mapping work in Step 2.

Step 2: Portfolio mapping exercise

Map projects, programs, or major initiatives onto the quadrants. For each activity, record its dominant intent, expected outputs, and relevant input characteristics such as scale, complexity, uncertainty, capability requirements, and resource intensity. Where the portfolio is too large, clustering may be used, for example by product line, customer segment, funding model, or technology domain. The aim is not perfect precision, but a sufficiently accurate representation of where effort is currently concentrated.

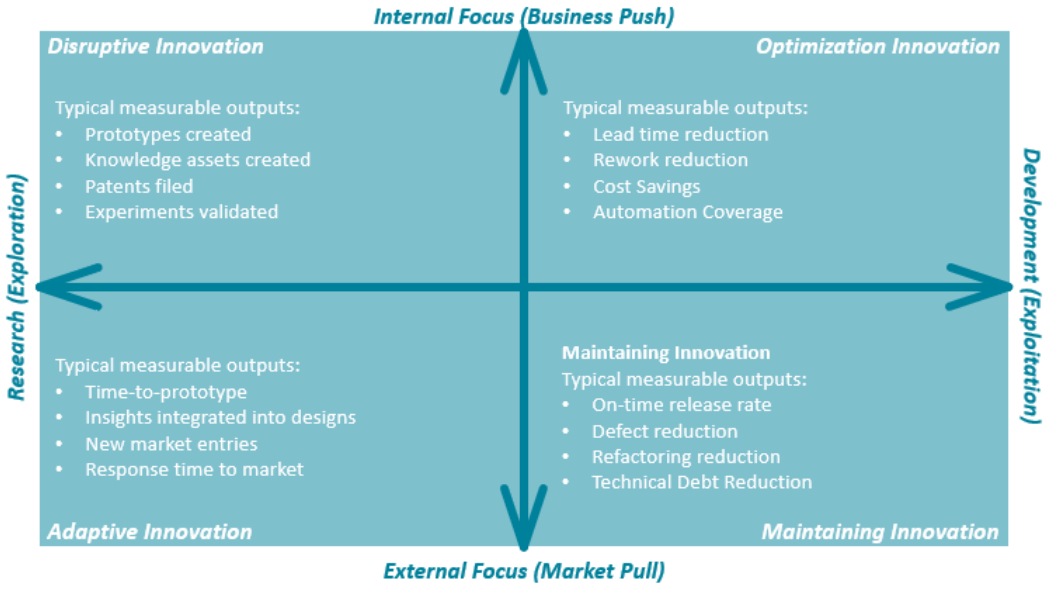


Figure 10: Typical outputs per quadrant as an example set for step 2.

Step 3: Reflection exercise
Reflect on the strategic intent reflection on the project / activities asking questions like:

- Which quadrant do you see your projects / activities today, and is that where you need to be?
- Has the portfolio succumbed to organisational drift? Because exploitation improves performance quickly and predictably, organisations naturally bias toward short-term optimization at the expense of long-term, uncertain exploration [69]. Does the current mapping reflect a deliberate strategy, or a structural drift toward safety?

Step 4: Consolidate the centre of gravity
Use the map and centre of gravity to assess whether the current distribution of work matches the organisation's intended strategy. Define the "blob" spanned by a set of projects criteria (e.g., per client, per funding model, per product of the portfolio, per industry, etc.) and determine its centre of gravity in terms of goal and success metrics.

- Are projects concentrated in the quadrants where the organisation believes it should compete, learn, stabilize, or improve?
- Are there projects or teams pulling the portfolio toward a mode of work that creates friction with leadership expectations, governance structures, or performance criteria?

This step is intended to surface misalignment, drift, and tensions between aspiration and actual effort.

Step 5: Define implications for productivity and management
The shape of the map carries diagnostic information. A portfolio weighted more heavily toward maintaining and optimization than intended suggests the organisation is consolidating when it expected to be exploring, and may need to charter feasibility work or rebalance funding toward disruptive and adaptive efforts. A centre of gravity shifting rapidly toward adaptive work suggests the external environment is changing faster than existing governance, cadence, or capability structures can absorb, and may require investment in the structures themselves rather than in additional adaptive work. Once the portfolio's position is understood, define what productivity should mean in each major part of it, including what counts as meaningful progress, which outputs are appropriate, what success criteria should dominate, and what management rhythm fits the nature of the work. The purpose is to ensure that teams are evaluated according to the strategic role they are meant to play, rather than against a generic or mismatched standard.

Step 6: Decide on actions and track movement over time
Translate the diagnosis into specific actions. If the disruptive quadrant is underweight, this may mean chartering a feasibility programme or ringfencing exploratory capacity. If exploitation is consuming exploratory capacity, this may mean sunsetting maintenance work or migrating engineers to adaptive teams. If risk posture is misaligned across layers per Section 4.4.1, this may mean adjusting governance and review cadence rather than reallocating people. Revisit the map periodically to confirm the portfolio is moving in the intended direction and that the associated success criteria remain appropriate.

The playbook produces a portfolio diagnosis and a directional prescription, but not a quantified improvement plan. After the six steps, an executive knows where the portfolio currently sits, where it should sit, and what kind of progress should count as productive in each part of it. What the playbook does not produce is a method for designing or measuring the specific R&D improvement projects that will move the portfolio in the intended direction.

This is the boundary at which the strategic framework ends. The quadrant model clarifies intent and reframes output. The playbook locates the portfolio and prescribes directional change. Beyond that, the conversation shifts from what kind of work is being done to how that work can

be improved and how the improvement can be measured. That is the subject of Chapter 5, which introduces waste reduction as the operational lens for designing and assessing R&D improvement projects, and the impact hypothesis as the device that links a proposed intervention to its expected effect on the three factors of the waste reduction formula.

5 Productivity Improvement

This chapter describes the second reasoning line that we have developed, viz., reasoning about productivity improvement by looking at waste reduction. The following subsections explain how this reasoning line can be used for R&D improvement projects.

5.1 Types of R&D Improvement Projects

We generally observe three basic types of R&D improvement projects:

Type	Project goal	Example
Faster	Perform some existing R&D activity in less time	Automation & Simplification
Earlier	Perform some existing R&D activity in an earlier R&D phase	Early system validation
Better	Perform existing R&D activities more extensively Perform additional R&D activities	System optimization Design for sustainability

In many cases, type “faster” is an enabler for type “better”, and these may be combined in a single R&D improvement project.

These three project types have very different effects on R&D productivity (after completion of the R&D improvement project):

Type	Effect on R&D effort	Effect on product quality	Effect on R&D productivity (= quality / effort)
Faster	Immediate saving	Same	Immediate increase
Earlier	Initial extra investment, afterwards saving (less rework)	Same (or higher)	Initial decrease, final increase
Better	Extra investment	Higher	Complicated / Situational

Based on this table, we conclude that R&D productivity is too limited to measure the impact of R&D improvement projects in general. Nevertheless, improvement of R&D productivity can be used as impact indicator: directly/short-term for “faster” projects, and indirectly/long-term for “earlier” projects.

5.2 Waste Reduction

Productivity improvement depends on removing factors like delays, rework, information gaps, decision uncertainty, coordination overhead, and unnecessary manual effort. Together, these factors constitute waste. As we have seen in our literature review in Chapter 2, the opposite of productivity improvement is waste reduction.

Waste reduction is about continuously finding and eliminating waste, and is more practical to use in the context of R&D improvement projects. As a formula for computing the waste reduction using a new or improved approach, we use:

Waste Reduction = # Engineers * Frequency * Saving

where:

- # Engineers: How many engineers have adopted the approach?
- Frequency: How often does a single engineer use the approach?
- Saving: How much is saved by one use of the approach?

For the saving, it is important to consider the potential scope of savings and include any relevant downstream effects. For example, changes in R&D may have an impact on R&D itself (both on the engineer and colleagues), but also on manufacturing, operations, business, etc.

When defining an R&D improvement project, it is important to identify the factors in the waste reduction formula that will be affected, and whether these indeed achieve the biggest impact. Technical specialists may be inclined to focus on the factor “saving”, but the other factors may be easier to influence. For example, imagine the feasibility of doubling the waste reduction by:

- Doubling the number of engineers using the approach, for example, by improving the user friendliness or by increasing the awareness within the organisation.
- Doubling the frequency that a single engineer uses the approach, for example, by extending the applicability of the approach or by sharing best practices.
- Doubling the savings caused by a use of the approach, for example, by making fundamental changes in the approach or by implementing additional techniques.

This reasoning not about the exact numbers (whether doubling the number of engineers exactly doubles the waste reduction), but to assess the potential of each factor in the waste reduction formula.

5.3 Impact Hypothesis

For managing R&D improvement projects, we propose to make an impact hypothesis both at the start and at the end of the project. In both cases, there are three interesting timepoints to consider:

- situation at the start of the R&D improvement project,
- (expected) situation at the end of the R&D improvement project,
- expected long-term potential after the R&D improvement project.

The situation at the start of the R&D improvement project is particularly relevant for follow-up projects where an earlier approach is further improved.

The impact can be expressed by providing/estimating concrete values for the factors from the waste reduction formula at each timepoint:

Timepoint	Number of engineers	Frequency	Saving	Total
Start of the R&D improvement project				
End of the R&D improvement project				
Long after the R&D improvement project				

5.4 Waste in Relation to the Quadrant Model

In Chapter 4, we have introduced the quadrant model for R&D productivity. Waste is a universal drag on R&D productivity and provides one of the most practical cross-quadrant measure that applies consistently across the entire portfolio. Once output is defined relative to quadrant intent, it becomes clear that no single output metric can span the entire R&D landscape. Because teams must optimize for fundamentally different outcomes—ranging from high-risk uncertainty reduction in early-stage exploration to strict, disciplined stability in mature products—these outputs cannot be collapsed into a common scale. The one element that all quadrants share is the presence of friction that slows progress. Waste takes different forms in each quadrant, but it always represents the unnecessary barriers that prevent teams from producing the type of output their quadrant requires. Waste is therefore the most transferable practical construct for identifying anti-productive conditions across the entire portfolio.

Although the outputs of quadrants differ, the obstacles that interfere with those outputs tend to fall into recognizable categories. Missing or unclear information slows learning. Excessive coordination overhead slows responsiveness. Unstable interfaces and unclear requirements degrade reliability. Redundant processes and manual steps reduce efficiency. These patterns appear in every organisation because they are functions of how knowledge work unfolds, not functions of the quadrant itself. The form of waste varies, but its consequences are consistent. It reduces the rate at which teams can convert input into the intended type of output for their quadrant.

Waste does not tell us what each quadrant should produce. It helps explain what prevents each quadrant from producing it. This distinction is important. Waste is more universal in principle than output, but less uniform in practice than a simple presentation might suggest. Different quadrants organise work differently, face different forms of uncertainty, and optimize for different success criteria. As a result, waste does not appear in exactly the same form across the portfolio. Missing information, excessive coordination overhead, waiting times, rework loops, unstable interfaces, unclear decisions, duplicated effort, and manual burdens may all be present, but their relative impact depends on the quadrant and the intent of the work [10].

The categories of waste may overlap substantially, but the consequences are still shaped by context [9]. For example, a delay in decision-making may be damaging in every quadrant, but not in the same way. In disruptive work, it may slow learning and prolong uncertainty. In adaptive work, it may reduce responsiveness to changing external signals. In maintaining work, it may interrupt reliable delivery and increase rework. In the optimization quadrant, it may preserve unnecessary complexity and prevent simplification.

The same diagnostic question remains across quadrants: what is slowing this team down in achieving its intended goal? As foundational knowledge-worker research suggests, improving productivity requires asking the workers themselves what hampers their tasks and needs to be eliminated [6]. That question creates a coherent way to diagnose friction across the portfolio. However, the answer may differ by quadrant, and so may the most appropriate response. A governance bottleneck, for instance, may need to be removed in adaptive work, while a recurring handoff failure in maintaining work may require stronger interface discipline rather than more speed.

Waste does not simplify the underlying work, but it does simplify how leaders, managers, and producers can talk about barriers to progress across heterogeneous teams. By focusing on avoidable friction rather than forcing all teams into one output metric, organisations gain a coherent way to compare where productivity is being lost without erasing the differences in what

each team is trying to produce. It gives leaders, managers, and engineers a common vocabulary for discussing barriers to progress, even when the work itself is heterogeneous. This is particularly valuable in R&D settings, where output cannot be normalized across all forms of work. By focusing on avoidable friction rather than forcing all teams into one output metric, organisations gain a more coherent way to compare where productivity is being lost. Waste therefore becomes the only universal constraint on productivity across the entire portfolio [9], [70], [75].

At the same time, the quadrant model remains necessary. Without it, waste risks becoming too generic to be actionable. The quadrant model clarifies what the work is trying to achieve. Waste analysis then clarifies what is getting in the way. Together, they connect strategic intent to operational improvement. The quadrant defines the nature of productive progress. Waste reveals where effort is being absorbed without contributing to that progress.

Waste is the right cross-quadrant lens not because it appears identically in every quadrant, but because the category applies universally even when the form does not. Every quadrant produces effort that is consumed without advancing intended output, but the specific friction (information gaps, coordination overhead, waiting, rework, handoff failure) and its operational consequence depend on what the quadrant is trying to produce. Waste reduction is therefore shared in principle and situated in practice, which makes it transferable enough to support cross-portfolio dialogue without flattening the diversity that the quadrant model exists to preserve.

5.5 Impact Playbook

Innovation and R&D thrive on speed, quality, and adaptability; however, hidden waste often slows down progress and erodes value. The aim of this playbook is to equip knowledge workers (e.g., R&D teams and relevant internal stakeholders) with a practical framework to identify and eliminate waste, improve productivity, and align R&D improvement projects with strategic goals. As such, building on the idea that by focusing on waste reduction as a universal lever, teams can achieve measurable impact across diverse R&D contexts without forcing a one-size-fits-all metric.

The following systematic approach is proposed to diagnose waste and define an impact hypothesis for an R&D activity:

Step 1: Setting the scene
Briefly explain the quadrant model and the pre-determined positioning of the R&D activity in scope (i.e., result of the Quadrant Playbook from Section 4.6). Highlight that waste is the common constraint across all quadrants.

Step 2: Identify your real task
As described in Chapter 2, following [6], each participant in the R&D activity should ask themselves:

- What is your task?
- What should it be?

Step 3: Map the current challenges
Each participant should continue by asking themselves:

- What hampers you in doing your task?

Ask each participant to list the top 3 sources of friction in their work (e.g., delays, unclear decisions, redundant steps). Group these into categories of waste sources, e.g., information gaps, coordination overhead, process inefficiencies, unstable interfaces, etc.

Step 4: Generate improvement opportunities
Explain the three types of R&D improvement projects (faster, earlier, better) and the waste reduction formula with its 3 factors (number of engineers, frequency, saving). Brainstorm about improvement opportunities and specifically aim for variety across types of projects and targeted factors from the waste reduction formula.

Step 5: Define impact hypotheses
For each identified improvement opportunity, estimate the potential waste reduction, and rank the improvement opportunities by total impact at three timepoints:

- Current state (at the start of the R&D improvement project),
- Expected short-term outcome (at the end of the R&D improvement project), and
- Long-term potential impact (beyond the R&D improvement project).

Step 6: Decide on an action plan
Choose the preferred improvement opportunity, define related actions and agree on how to measure success.

6 Conclusions and Further Work

Our first research question from Section 1.2 was:

> "*How can R&D productivity, as seen by the Dutch high-tech equipment industry, be better understood and incorporated into the design, execution and impact measurement of R&D improvement projects?*"

As discussed in Section 4, there is no generic definition of R&D productivity that works across all organisations or even within a single organisation with a diverse product portfolio. R&D productivity should be reframed as a context-dependent concept aligned to project intent and stakeholder goals. We have introduced a framework with 4 quadrants:

- Disruptive innovation
- Adaptive innovation
- Maintaining innovation
- Optimization innovation

that explains the different perspectives on productivity in the Dutch high-tech equipment industry. Specific R&D improvement projects should reflect quadrant-specific priorities and trade-offs.

Our second research question was:

> "*How can metrics for industry R&D be adapted to reflect on productivity in R&D improvement projects?*"

As discussed in Section 5, there is no single, easy-to-measure metric that captures R&D productivity. However, the opposite of productivity improvement is waste reduction, and this is more practical to use in the context of R&D improvement projects. We propose to develop impact hypotheses at the start and the end of an R&D improvement project in terms of the factors from the waste reduction formula.

Although this study focused on the Dutch high-tech equipment industry, we expect that the results generalize to a much broader context. We realize that many of the ingredients from this report may be generally known. The added value of this report is to articulate them and to create some workable reasoning lines.

In addition, we observe a couple of recurring themes throughout the chapters:

- Artificial intelligence, as technology with high expectations regarding productivity.
- Change management, as step to implementing productivity improvements.
- Employee satisfaction, as factor influencing knowledge worker productivity.
- Quality over quantity, as a characteristic property of knowledge work.
- Tacit knowledge, as aspect of knowledge work that can hinder productivity.

These may require additional attention when working on R&D productivity.

To conclude, we sketch some directions for further work:

- Scientific studies of the impact from technologies like AI and MBSE on productivity.
- Effective methodologies for knowledge sharing that enhance productivity.
- Data-driven methodologies to prioritize waste reduction initiatives.

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