# A systematic approach for identifying fundamental successes and failures on complex product development programs

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# Abstract


A systematic approach for identifying fundamental successes and failures on complex product development programs

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Organizations invest substantial resources to implement generic product development (PD) processes as a means to manage the development of high-complexity products. The difficulties reported on recent aircraft development programs suggest that manufacturers may not be fully benefiting from these tools. There is an opportunity for organizations developing complex products to learn from completed programs as a means to make informed improvements in their generic PD processes. Existing research supports that learning from projects in this way is mostly unsuccessful in industry. The lack of sophisticated project learning techniques capable of managing the complexity inherent to complex programs is a limiting factor to realizing this opportunity.

The purpose of this research project was to study an archived development program in order to extract useful information pertaining to the host organization's PD process. A case study of an aircraft development program was undertaken to gain insight into the root causes of the program's considerable schedule overrun. This included developing an approach for untangling the program's non-intuitive behaviour and identifying the fundamental successes and failures of its execution. A mixed-methods research design incorporating quantitative and qualitative methods was developed and implemented. Additionally, an adapted thematic analysis (TA) method augmented with elements of qualitative content analysis (QCA), thematic networks (TNs), and causal maps was formulated for this investigation.

The results of the case study included a tiered catalogue of root causes driving the program's outcome and a map of their causal linkages. These themes are uncovered lessons pertaining to the host organizations PD process and the fundamental successes and failures of its actual execution. These results are of value to the host organization and empower it to make informed improvements in its processes. They are also insightful for any organization undertaking complex PD. The overarching result of this study is ultimately the research design itself as an effective mechanism for systematically identifying the root causes of a complex development program's outcome and untangling their interactions. This result is an explicit contribution to the need for more sophisticated organizational project learning mechanisms specifically applicable to complex programs. Moreover, it is an enabler to developing a full-fledged process for making closed-loop improvements to PD processes as a means to achieve their ongoing improvement.

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# Chapter 1

# Introduction

*In the first chapter of this thesis,* the reader is provided with the necessary background information to contextualize the topic and is presented with the specific research problem. The purpose of this study, the motivation for undertaking it, and *how* it was carried out are also made clear.

## 1.1 Introduction

*How can organizations learn from completed PD programs to improve existing PD processes?*

This thesis investigated an archived product development (PD) program in the context of a mature aircraft manufacturer as a case study to support the ongoing improvement of generic PD processes. Valuable lessons pertaining to the fundamental successes and failures of the program's execution were uncovered. Ultimately, the overarching contribution of this work is an approach for organizations developing complex products to systematically analyze archived programs in order to draw non-easily identifiable lessons and connect causes to outcomes. This work advances existing understanding of project learning techniques suitable for complex programs and is an enabler to developing a full-fledged process for making closed-loop improvements to PD processes.

## 1.2 Background to the research topic

This section outlines the three areas that overlap this study and highlights the importance of research in each of them.

### 1.2.1 Commercial aircraft manufacturing

The global commercial aerospace industry is vast in scope and encompasses a variety of different sectors. It includes the *buyers* and, of specific interest here, the *manufacturers*. Demand on *manufacturers* for business comes directly from *buyers*. The dynamic is such that "air transport growth is the key commercial driver of new aircraft sales, a major 'pull factor' for growth of aircraft manufacturing."[1, p. 12]. The expected growth in air travel of both passengers and freight [2] is a good indicator for the entire industry as more passengers and freight to move translates to an increased demand for aircraft.

This evolving industry outlook has important implications for the already competitive commercial aircraft manufacturing market. As new business opportunities become available, manufacturers will need to contend with heightened competition to secure market share [1][3]. This requires distinguishing oneself by developing high performing and quality products, delivering them on time, and at a cost that is both profitable and less costly than the competition [4, Ch.1][5, pp. 18-19].

The current state of aerospace development programs is characterized by schedule delays and budget overruns. Statistics from a 2016 industry wide study found commercial development programs experience schedule delays in the range of 2 to 4 years and budget overruns of $6 to 8 billion USD [6]. Comparative numbers for US defence programs found average schedule delays of 29.5 months and average budget overruns of 48.3 %. The difficulties experienced in managing and executing PD programs have existed in the aerospace industry for decades and are projected to persist [7].[1] For the organizations involved, the consequences of late and over-budget programs include:

- negative publicity,
- declining share prices,
- contract penalties,
- lost market share, and
- demoralized workforce [10, p. 4].

Despite the difficulties in managing and executing aircraft development programs, organizations still succeed in designing and developing commercially and technologically successful products. However, with increasing levels of complexity and the growing need to reduce development cycle times, Eckert and Clarkson note that "[...] more and more pressure will be put on the design and development processes"[11, Sec. 8]. Given the central role of such processes in PD, improving them to be evermore effective and efficient is a key enabler to meeting evolving needs. Therefore, in the uniquely challenging context of commercially financed aircraft manufacturing, research aimed at improving design and development processes is worthwhile.

### 1.2.2 Product design and development processes

*Product development* as defined by Ulrich and Eppinger [12, p. 2] "is the set of activities beginning with the perception of a market opportunity and ending in the production, sale, and delivery of a product." The product development effort is generally undertaken within the context of an enterprise as a *project* executed by an interdisciplinary team supported by all functions in the organization. Product development efforts in aerospace are generally referred to as *programs* instead of *projects* in consequence of their scope. Product development ventures are high risk financial decisions for any firm. From the outset, there is no guarantee that product sales will generate enough revenue to recoup costs and generate profit.

The *product development process* is the sequence of activities an enterprise uses to execute *product development*. Any firm undertaking product development has a process for doing so, whether it is defined at every step or ad-hoc in nature. The term "process" is used to refer to either the generic high-level procedure prescribed within an organization or the actual sequence of activities

[1] Note that such difficulties in managing and executing large-scale projects (programs) are not unique to the aerospace industry and have been observed on programs of *all* types [8][9]. Furthermore, even though the specific context of this study was the aerospace industry, this work is pertinent to complex commercial product development programs in general.

that occur in practice [13, p. 4, 61].[2] The concept of a *process model* is distinguished from a *process* in that process models are abstracted representations of actual processes.

Across organizations, PD processes vary according to their level of definition and type of model they follow. It is also not unusual for firms or individual engineers to not fully understand the process through which they develop products or designs [14, p. 162]. This is especially true in cases of large-scale and technically complex developments as in aerospace. Product design and development processes are distinguished from other business processes according to scale, novelty, infrequency, iteration, and uncertainty [11][14]. As such, these processes are notoriously difficult to understand, and modelling and planning them is problematically ambiguous [13, Ch. 2]. Some authors refer to this characteristic of PD processes as "opacity" [10] and identify it as a cause for the cost and schedule overrun described in the previous Subsection 1.2.1.

Product development has been the focus of extensive research since the 1960's. Motivation stems from the accepted consensus regarding it as a necessary activity for corporate survival and financial prosperity [15, p. 3][16, p. 3]. Pursuing a deeper understanding of PD processes enables firms to support and improve them [14, p. 162]. Ultimately, the goal as put by Eckert and Clarkson [13, p. 22] "is to make a process more effective and efficient in order to ensure that a sufficiently good product will be developed on time and on budget". Thus, in the larger context, for these aircraft manufacturing firms that means:

- enhancing their ability to compete in competitive environments,
- mitigating the cost and schedule overrun on PD programs, and
- reducing the risk borne by undertaking PD programs.

To emphasize the importance of PD processes in the context of commercial aircraft manufacturing, Altfeld notes that manufacturers no longer compete on technological grounds but rather their mastery of PD practices [5, pp. xv - xvii].

### 1.2.3 Project learning

*Learning* (to some degree) is an inherent part of undertaking any project [17, Ch. 2]. In addition to product delivery, some authors consider the knowledge created through projects as a primary output of the endeavour [18][19]. How organizations learn from projects—or alternatively "project learning"—is a broad topic. According to Williams [17, Ch. 2], project learning touches on the theoretical underpinnings of *knowledge* and *learning* at the level of the individual, and *organizational learning* and *knowledge management* at the level of the organization.

In understanding the existence of *knowledge* in organizations, authors Nonaka and Takeuchi [20] extend the concept that knowledge can be "explicit" or "tacit". *Explicit knowledge* can be codified (i.e. expressed using words and numbers) and is easily communicated. Alternatively, *tacit knowledge* is neither easily expressed nor easily communicated as it is "highly personal and hard to formalize" consisting of know-how and ingrained beliefs [20, p. 8]. The relationship between *knowledge* and *learning* is described in the literature as "iterative" and "mutually reinforcing" [21, p. 493]. Learning is regarded as a process for increasing knowledge (acquiring and creating it), in turn shaping future learning [19][21][22].

Learning at the level of the organization—i.e. *organizational learning*—is defined by Duhon and

[2] In this text, the distinction between both meanings is made clear in cases of ambiguity.

Elias as:

> "[...] an increase in the knowledge or skills of individual members of the organization or a change in the structure, processes, or culture of the organization that enables the organization to be more effective at planning and implementing actions that achieve the organization's objectives."[22, p. 5].

Organizational learning thus includes activities for (i) increasing knowledge, (ii) storing/sharing it, and (iii) using it for change [19, p. 63]. Reference [22, p. 5] compares how humans and organizations learn; *we* learn by processing information through our central nervous systems, whereas organizations with no such intrinsic structure require dedicated mechanisms for learning. Organizations without such dedicated mechanisms may still be capable of learning, albeit at a mostly degraded capacity. There are a number of project learning processes and techniques that have been developed in academia and in practice, one prominent example being "lessons learned" from the Project Management Body of Knowledge [23]. A major focus for this study is on the deliberate efforts of organizations to learn from projects.

The importance and worthiness of project learning efforts in organizations is well established in the research literature. In their 1995 study, Nonaka and Takeuchi [20, Ch. 1] theorize on the importance of *knowledge* as the "new competitive resource" by which firms will outperform each other in the future. Although it is difficult to comment on whether or not this view materialized, the need for effective project learning is still sought after. Apparent motivating factors for organizations to learn from projects are to minimize repeating mistakes and losing knowledge. The latter is of special importance in aerospace development programs where contractors sometimes leave the permanent organization with crucial knowledge. This is also relevant in cases of aging workforce turnover termed "brain drain" [24]. Project-based organizations are especially susceptible to these risks as the structure is not conducive to sharing the knowledge and experience gained by individuals and teams with the permanent organization [17, Sec. 2.2]. Project learning is instrumental for the adaptability and responsiveness of organizations in the long-term [19].

### 1.2.4 Synthesis

The research that is the subject of this thesis is positioned at the intersection of the three areas correspondingly outlined in the three previous subsections. This context is illustrated in Figure 1.1.

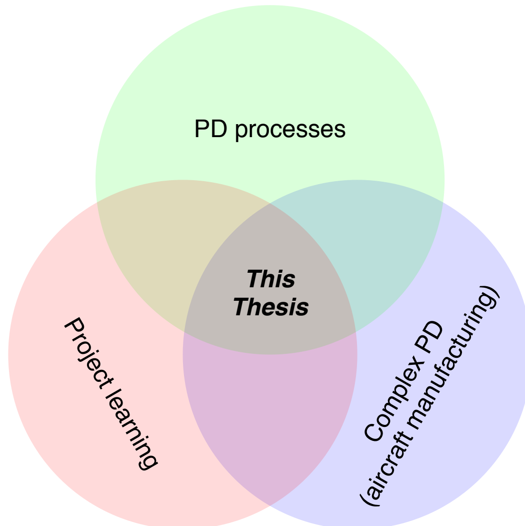


Figure 1.1: Context of *this* research project.

## 1.3 Problem statement

This section highlights the specific research problem addressed by this study by first examining the intersection of this problem in relation to each of the individual areas.

### Aircraft development programs tend to overrun budget and schedule

Aerospace original equipment manufacturers (OEMs) are under pressure to improve their performance on PD programs by developing products of superior quality, shortening development cycle times, and reducing product costs. Many organizations have already made investments towards improving their PD practices [5, pp. xv - xvii]. Reports on recent development programs, however, indicate that organizations still have difficulty managing and executing PD programs that meet baseline objectives of budget and schedule. Ultimately, for these organizations undertaking complex developments, there still remains opportunity for improvement in the management and execution of these programs.

### PD processes require ongoing improvement (closed-loop feedback)

Organizations invest substantial resources to implement generic PD processes as a means to manage the development of high-complexity products. Existing research indicates that the mismatch between the claimed benefits of generic PD process models and those observed in practice are the result of their inadequate implementation [25]. For process models to be effective, the generic PD process must be adapted to the specific approach existing within the organization, which in turn requires a fundamental understanding of the way work is actually done (i.e. the underlying process) [26]. Given the unique complexity of the aircraft design and development process, developing such an understanding is especially difficult in that context. Ultimately, closed-loop feedback from completed PD programs can be used to converge generic PD process models to more closely match the actual underlying process. Although some closed-loop feedback techniques exist, they lack the procedural guidance and sophistication to be readily implemented and effective in organizations undertaking complex development programs.

### Mechanisms for learning from complex projects are limited

Although the benefit of closed-loop PD process feedback for ensuring the effectiveness and long-term use of PD processes is known, learning from projects in this way does not seem to be particularly successful in industry [17][27][28][29]. Existing research identifies the limitations with common project learning techniques and more specifically their application to complex programs [22][28][30]. These techniques may be sufficient for straightforward projects, however, they lack (i) the practical guidance to be workable in large organizations and (ii) the robustness required for identifying non-trivial lessons from complex programs. There is a recognized need for further research aimed at "promoting learning in project-based organizations" [19, p. 71] and, more specifically, a call for more effective learning mechanisms and techniques [22, p. 7][30, p. 450][31, p. 278]. In consequence of this need, organizations developing complex products are limited in their ability to learn from their experiences on completed PD programs.

### Synthesizing the specific research problem

There is an opportunity for aircraft manufacturing organizations to improve their performance on future development programs through the ongoing improvement of their existing PD processes by systematically learning from completed development programs.

## 1.4 Research purpose, motivation, and description

This section makes explicit the contribution of this study to addressing the specific research problem and the motivation for undertaking it. Also included is a brief summary of the methodology.

### 1.4.1 Purpose statement

The purpose of this research was to study an archived development program in order to extract useful information pertaining specifically to the host organization's PD process. That included developing an approach for untangling the program's non-intuitive behaviour and identifying the fundamental successes and failures of its execution. The intention was such that extracted lessons could later be used by the host organization to inform improvements in their generic PD process framework.

### 1.4.2 Research motivation and description

This research project was undertaken as part of a broader campaign to modernize and improve a mature aircraft manufacturer's generic company-level PD process framework. Of particular importance to this improvement campaign was the objective of reducing the degree of schedule overrun on programs undertaken by this organization. Given this motivation, the case study of an aircraft development program was undertaken with the initial intention of developing new understanding of *why* aircraft development programs went over schedule in this organization's context. What emerged however was a greater look at project learning and *how* non-easily identifiable lessons could be extracted from completed PD programs.

# Chapter 2

# Literature review

*In the second chapter of this thesis,* the body of literature encompassing the topic is examined and the existing gaps within it are made clear. This review is a strategic look at current and typical industry practices.

## 2.1 Introduction

Since the 1960's, there has been extensive research into *product development* (PD). As a reflection of its interdisciplinary nature, academic research has emerged from many domains including project management, marketing, operations management, systems engineering, and the various traditional engineering fields. The vocabulary encompassing the topic is equally diverse, many synonymous terms and keywords exist specific to their domain of origin. The diversity of research has contributed to a siloed body of work that has been described as "extensive", "complex", "disparate", and "often confusing" [15][32]. The popularity of "product life cycle management" and the volumes of consultant and vendor grey area literature also further complicate the topic [33].

The focus of this review is on outlining a clear narrative that OEMs typically follow in their efforts to improve product development practices within their organization. The objective is to frame the limitations in current practices which this work aims to address.

## 2.2 The product development process

*Process* has been the object of extensive research from a number of different perspectives [34]. A subset of that work has been at the intersection of *product development* and *process*. The research philosophy behind *PD processes* extends process-management thinking to the activity of product development [35]. On the topic of PD processes, Browning writes:

> "Every organisation, team, or individual that does work and produces results has a process – a set of actions and interactions. That process may not be documented, modelled, effective, efficient, consistent, or understood, but it is the actual way the work occurs." [36, p. 538]

Processes thus exist as (i) *reality*—the way work really gets done—and (ii) *models*—abstract representations of the way work can or should be done [11][37]. The distinction between the two is not always explicit.

*Practitioner understanding* of process in organizations responsible for designing and developing products is discussed in references [11, Sec. 6.4][38]. For complex products, an individual's overall understanding of the process from kickoff to delivery, as put by Eckert and Clarkson, "...is almost inevitably partial" [11, p. 167]. It necessitates a broad knowledge of the product—i.e. technical knowledge—and the ways in which the organization works—i.e. organizational knowledge. Gaining such knowledge is affected by an individual's role in the organization and level of experience. Ultimately, practitioners possessing this knowledge are rare [38]. Developing an understanding of the underlying PD process is especially difficult in the aerospace industry given the sheer scope of such undertakings, their globally distributed nature, and long development lifecycles that can last upwards of 10 years.

## 2.3 Models of the product development process

In understanding *why* we model processes, reference is made to a fundamental proposition of PD process modelling theory, which asserts:

> "Processes can be regarded and treated as *systems* that should be engineered purposefully and intelligently, facilitated by useful models [Negele, Fricke, and Igenbergs, 1997; Pajarek, 2000]". [37, p. 106]

Of the systems comprising a PD program, authors Negele, Fricke, and Igenbergs [39] identify *process* as the central unifying element. It is the centre of connection between the organization, the product, and the established objectives. As expressed by Browning et al., "[i]f the project were a sentence the process would be the action verb" [37, p. 108]. These authors investigate the fundamentals of process modelling in PD as well the purposes they fill. In brief, process models are valuable tools for representing, understanding, engineering, managing, and improving the PD process [40].

### 2.3.1 Overview of engineering design and development process models

PD process models evolved out of the early engineering design models [41][42], which generally limit consideration to only the design aspect of development. A wide variety of PD process models and modelling techniques have been published in the literature. Techniques and models are distinguished according to a number of different dimensions.

Browning and Ramasesh [40] provide a survey of network-based PD process models using an organizing framework according to model purpose. Eckert and Clarkson [11][43][44] review process models and modelling techniques from the perspective of planning development programs. Wynn and Clarkson [14] provide an extensive review of design and development process models using a two-dimensional organizing framework according to *type*—or intended purpose—and *scope*—or level of definition.

With respect to model *type*, different classification schemes exists in the literature [45], however, they are commonly typified as either *prescriptive* or *descriptive*. *Prescriptive* process models direct how work *should* be done by defining best practice and *descriptive* process models capture the way work *is* done [46, Ch. 2]. These types are also respectively denoted as "to-be" and "as-is" models. With respect to model *scope*, using the terminology from reference [14], the level of resolution varies from the *micro-level*—individual process steps—to the *macro-level*—overall project/program structure. These high-level process models are also sometimes called "canonical" models [37]. The focus of this review is directed to *macro-level* PD process models of the *prescriptive* type.

### 2.3.2 Prescriptive macro-level PD process models

*Macro-level* models structure developments at the highest level, defining which activities comprise the program, their arrangement relative to each other and dependencies between them [40, p. 224]. A number of prescriptive macro-level PD process models have been published in the literature, popular examples include (i) the *stage-gate* process model [12][35], (ii) the *spiral* development model [47], (iii) and the systems engineering *"Vee"* model [48][49]. Wynn and Clarkson [45] engage a comprehensive review of this model type.

There have been notable contributions to PD process research from the field of software engineering [50]. Some field specific macro-level models are reviewed in references [46][51, Ch. 7]. Note that the stage-gate process model is typically referred to as the "waterfall" process in this domain, a reflection of its one way nature. The focus of this review is directed to this specific process model.

## 2.4 The stage-gate process model

Phased development processes are widely used in industry. They are most typically referred to as "stage-gate" processes, although a number of alternative terms exists including phase-gate, tollgate, and waterfall.

### 2.4.1 Origin

The stage-gate process can be traced back to the 1960's at NASA and their "phased project planning" (PPP) policy [52]. The approach defines discrete program phases segmented by decision points [53]. Morris in reference [54] investigates the inception of this concept in greater depth. NASA's official implementation of the method in 1965 on the Apollo lunar program coupled with their "technical review process" [55] brought these practices to the attention of industry and academia, thus marking the start of its proliferation into the mainstream.

### 2.4.2 The generic concept

Stage-gate models represent the development process as a linear series of *stages* (or phases) delineated by checkpoints called "gates". Each stage defines activities for the program to execute, i.e., a set of prescribed outputs. Gates control whether the program passes to the following stage by way of *entry* and *exit* criteria. These are formal reviews that represent hard stops to assess the program. Gates serve a threefold purpose (i) to ensure the program accomplishes the intended outputs of each stage, (ii) to act as "go", "no-go" or "terminate" decision points, and (iii) to plan the following stage. Ulrich and Eppinger [12] and Cooper [35] examine the mechanics of the generic traditional stage-gate process model. It is presented in Figure 2.1, reproduced from Cooper [52].

The philosophy behind this family of process models, as put by Cooper is to "bring discipline to

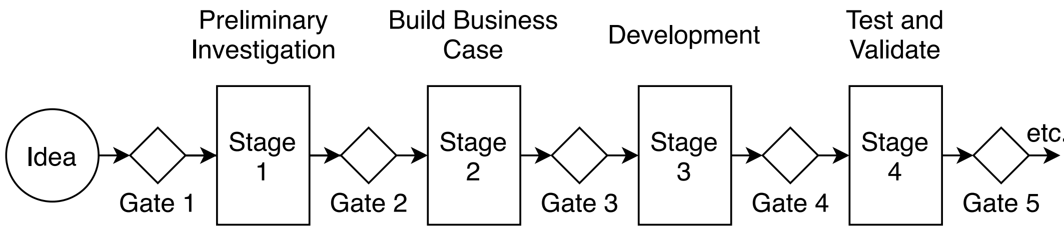


Figure 2.1: Generic traditional stage-gate process model as per Cooper [52].

an otherwise chaotic, ad-hoc activity" [52]. This regimented approach to development aims to minimize the risk of costly *rework*, i.e., "going back to revisit a supposedly completed [stage]" [56]. The methodological development of a product through this model is stable but inflexible. Drawing on the *waterfall* analogy, going back upstream is possible, however, onerous. Unger and Eppinger examine this strategy to iteration in the context of risk management in references [56][57].

The *traditional* stage-gate process is characterized by discrete phases without any overlap separating them. Cooper [52] reports on the limitations of this model in practice. Some weaknesses include (i) inefficiency and lack of pragmatism from the explicit delineations and serial workflow and (ii) excessive comprehensiveness, rigidity, and bureaucratic overhead. In order to address these limitations, modified versions of the traditional stage-gate process have been proposed. These are reviewed in references [12, Ch. 2][51, Ch. 7][52].

### 2.4.3 Implementation in organizations

The preceding section focused on the *generic* stage-gate process model of a PD program. Tzortzopoulos [25] investigates the implementation of such generic PD processes for use within specific organizations. Implementation includes *adopting* the generic process into an organization and then *adapting* it first, to the organization's context and second, for the project under consideration. The author's illustration of the implementation of generic PD processes at different levels of generality is adapted for use in Figure 2.2. It highlights the different levels of adaptation firms undertake in implementing a generic PD process. Browning et al. [37, Sec. 3.6] use the terms "standard" and "deployed" processes to refer to the company-level and project-level processes, respectively. *Standard* company processes are prescribed for use on all projects and following adaptation (or tailoring) they are *deployed*.

In practice, company-level generic PD processes or systems, are sometimes called "NPI Processes" [11] and are typically assigned proper names, for example, Procter & Gamble's SIMPL (Successful Initiative Management and Product Launch) [58, p. 541]. A number of organization-specific stage-gate PD processes are accessible in the public domain. Authors Chao and Ishii conducted the benchmarking of some of these processes, including that of ABB, General Electric [59], and NASA [60]. Note that company PD processes may also be supplemented by additional business process tools and techniques, including Design for Six Sigma (DFSS) and Total Quality Management (TQM).

The implementation of generic PD processes is often identified as the limiting factor preventing organizations from enjoying their espoused benefits [58]. Adopting these processes entail significant

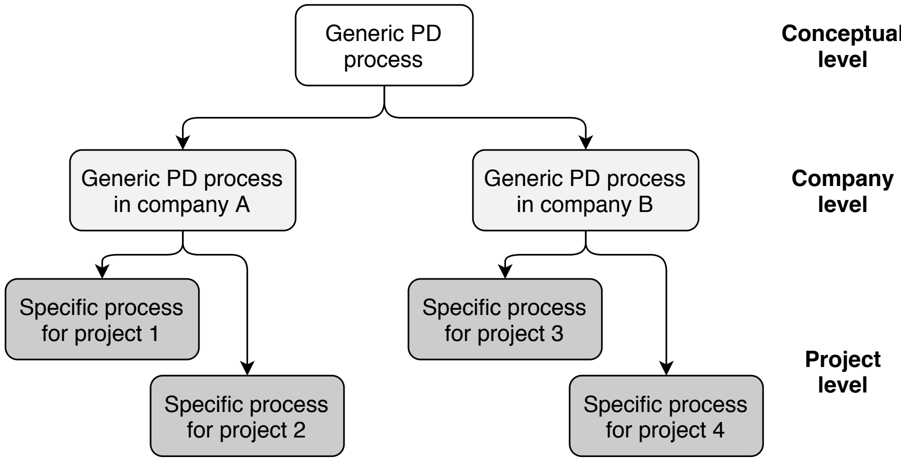


Figure 2.2: Implementation of a generic PD process at varying levels of generality, adapted from Tzortzopoulos [25, p. 24].

changes within an organization's existing structure and workflow, impacting people, processes, and IT infrastructure [25, p. 40]. These changes can cause intra-organization tension and require substantial investment in effort and cost [58, Ch. 11]. Cooper [35, p. 45] cites the case of Northern Telecom in the 1980's which cost the organization approximately $1 million to design and implement a company-level stage-gate system. Adjusted for inflation (in 2020), that cost is approximately $2.4 million.

Process implementation in mature organizations is itself a broad topic. Tzortzopoulos provides a review of the existing literature from the perspectives of process management and organizational change management [25, Ch. 2]. This author argues that the mismatch between the claimed benefits of generic PD process models and those seen in practice are the result of their inadequate implementation. Both Tzortzopoulos [25] and Cooper [58] agree that PD process implementation is complex and crucial for fully benefiting from process models.

Ultimately, efforts to implement a generic PD process in an organization are more likely to be successful if they are effectively adapted to the company context [25, p. 249]. Therefore, although there are many publicly accessible generic stage-gate process templates [58, p. 522] organizations still require an intimate understanding of their existing PD processes in order to adapt the generic model [26]. The generic PD process should be augmented to the specific context and approach existing within the organization, which in turn requires a fundamental understanding of the way work is actually done (i.e. the underlying process). However, as noted earlier, developing an understanding of an organization's underlying PD processes is itself an obstacle [11, Sec. 6.4].

### 2.4.4 Phased development processes in aerospace

Most organizations typically adopt a custom company-level stage-gate process model as their top-tier generic PD process [11, p. 158][14, p. 194]. So far, this review of PD literature has been generic to any industry. In this subsection, the focus is narrowed specifically to examples from aerospace. Altfeld [5, Ch. 3] provides examples of specific phased PD processes that were adapted to the project/program-level for actual commercial aircraft developments. These are reproduced in Figure 2.3. This figure emphasizes the customizations organizations make to their specific project-level processes with respect to the number of phases and required milestones. The stage-gate philosophy, however, remains the same in that programs only proceed to the following stage given all predefined outputs are achieved and authorized as per the gate (or milestone) decision.

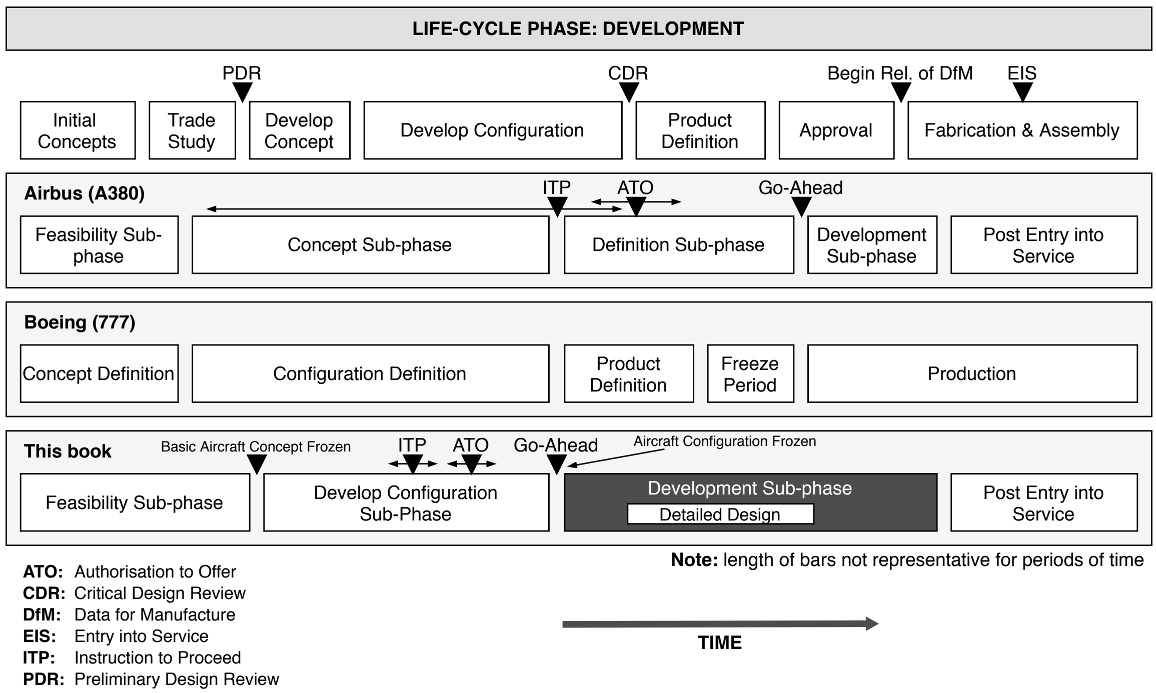


Figure 2.3: Examples of program-level specific PD processes for commercial aircraft, reproduced from reference [5, p. 50].

### 2.4.5 The realities of PD process models in practice

PD process models are ultimately a practice-oriented means for improving and managing processes. It was noted that the research effort sometimes misses this focus by over emphasizing theory [14, pp. 194-195][25, p. 25][45, p. 55]. With respect to the realities of applying these process models in practice, Altfeld explains that despite the rigid reviews, in industry “pressures emanating from the necessity to protect the programme [sic]” [5, p. 49] lead to bypassing gates with unfinished deliverables. Furthermore, in reality, macro-level process models guide the program at large, but offer minimal day-to-day guidance. Such macro-level models serve more as mental models for practitioners to align their involvement on the program [5, p. 49]. Generally, a fragmented set of additional process models exist in companies at various levels of definition and purpose that are specific to the functional groups using them [14, pp. 194-195]. These are sometimes filed together in a company process architecture or framework, although they are seldom integrated together [37][61].

## 2.5 The ongoing improvement of PD processes

The preceding sections reviewed existing literature pertaining to the design and implementation of PD process models. In this section, the focus of this review is directed to mapping the research conducted in the ongoing improvement and updating of these models following their initial adoption and adaptation into organizations.

### 2.5.1 Closed-loop PD process feedback

Industry practitioners and academics have long recognized the need for PD process feedback. The concept of closed-loop feedback involves using the experiences gained from an actual PD project to update the knowledge content of the generic process model [25, pp. 251-4]. Lessons from deploying the process model and executing the project (underlying process) are captured, analyzed, and embedded into the standard process [37, Sec. 3.6]. *Fundamental successes* are distilled to be routinized throughout the organization and *fundamental failures* are addressed to prevent future repeat. As such, the generic PD process model is dynamic and constantly updated to reflect new organizational knowledge. Figure 2.4 expands on Figure 2.2, in order to illustrate the concept of closed-loop feedback.

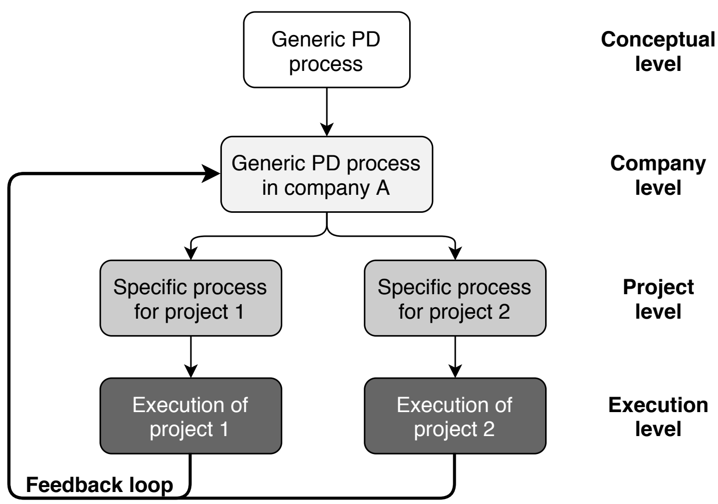


Figure 2.4: The closed-loop feedback of product development processes.

Closed-loop feedback is a key aspect of converging the design and implementation of a process model to fit a particular organization. Each cycle of learning (i.e. iteration) captures knowledge pertaining to the development's execution which is then distilled and reflected in the generic company-level process model. Browning et al. [37, Sec. 3.2] note that PD process models in dynamic organizations are never completely accurate. However, such feedback helps close the gap between generic process models and the actual underlying process, and serves to identify opportunities for process improvement. Moreover, it increases the likelihood that a generic process model remains in use within an organization for the long-term as practitioners are more inclined to regard it as a value-adding tool [25, pp. 251-4][58].

The ongoing improvement of PD processes using feedback from past project experiences overlaps the research surrounding *how* organizations learn from projects, i.e., *project learning*. This is the subject of the following subsection.

### 2.5.2 Project learning: Lessons learned

Project learning is itself a broad topic that encompasses the theoretical underpinnings of *knowledge*, *learning*, *organizational learning*, and *knowledge management*. Authors Brady et al. [62] comprehensively examine all explicit and implicit learning practices in project-based organizations responsible for developing complex products. Williams [17, Ch. 2][27] provides a review of these fundamental project learning concepts as well as an extensive survey of *lessons learned* practices from a project management perspective. The focus of this review of the project learning literature is directed to the deliberate efforts of organizations to learn from projects.

The term “lessons learned” can be ambiguous as its meaning differs between industry and academic settings. It is used to refer to (i) the mechanism commonly used in practice for learning from project experiences, (ii) the new knowledge outputs from (i), and (iii) “the learning (in its various forms), that takes place throughout a project and between projects” [63, p. 14]. As a mechanism used in practice, the term is synonymous with *postmortems*, *post-project audits*, and *retrospectives* [63, Table 1]. Popular definitions of this term defined by major organizations are compiled in reference [64, p. 18].

Duffield and Whitty [28] report that in the established literature, lessons learned processes are mostly variations of three essential steps (i) identification (capture), (ii) dissemination (transferring), and (iii) application (implementation). The authors describe each step as follows:

- *identification* is the collection and analysis of lessons,
- *dissemination* is the distribution of such lessons around the organization, and
- *application* is the incorporation of lessons (new knowledge) into organizational action.

These same authors note that the first step of the process is often mistaken as a complete lessons learned process.

Although the importance of project learning is well reported, according to Williams [17, Sec. 2.4.2.] the literature is split on the prevalence and success of such techniques in practice. In a survey of 522 project practitioners, this same author reports that while 62.4% of respondents' organizations had formal processes for learning lessons, only 11.4% actually adhered to such processes, and only 8% think enough effort was invested in conducting lessons learned processes [17, Ch. 3]. Authors in references [17][27][28][29] agree that most lessons learned processes do not seem successful in attaining their intended purposes. In summary, most organizations are not benefiting from lessons learned processes to successfully learn from projects to improve future performance.

Standards and guidance exists for deriving lessons from projects, although authors have pointed out the lack of pragmatic advice in the literature. Duffield and Whitty write:

> “Generally speaking, there are many opinions and guides, but little practical advice regarding workable processes that effectively enable the organisation [sic] to learn from past project experiences.” [28, p. 312].

The PMBoK Guide [23] is often cited as one such standard that has been critiqued by a number of authors [17, pp. 27-8][28, pp. 312-3][63, pp. 18-9] for providing little operational and procedural guidance and being overly simplistic.

Williams in references [30][31] highlights the problem with these existing means for project learning. This author argues that they may be sufficient for simple projects but do not scale to complex programs. Learning from complex development programs is particularly difficult because of their inherent characteristics, of which some include project-based organizational structures, their unique and temporary natures, non-intuitive project behaviour, multiyear development lifecycles, and high degrees of complexity (technical, systems, and organizational) [62][65]. On these complex programs, identifying and understanding the root causes of project outcomes is significantly more difficult than merely collecting data [17][27][29][30][31]. Identifying the "hard", non-trivial lessons from complex programs calls for more sophisticated means to analyze their counter-intuitive behaviour.

In the context of complex programs, Cooper et al. [29] outline a framework for a sophisticated learning system for general project management lessons, however, these authors do not indicate how to identify underlying causal factors to a program's outcome. Although some forensic techniques for this specific application do exist, Williams notes that they are too exhaustive and labour-intensive for implementation in industry [30][31]. This author identifies the need for an effective and easily implementable method for drawing non-obvious lessons from complex programs in a short time span [30, p. 448]. Moreover, Williams [31] demonstrates the utility of cognitive/causal mapping in understanding complex cause and effect relationships inherent to complex programs. This author concludes that more research is needed into the operationalization of routine organizational learning processes in regular practice.

Some additional points relevant to project learning are summarized below.

- Standalone lessons learned systems have had limited success in organizations. Although they often contain significant knowledge, they are seldom used by practitioners for reasons including (i) their representation of lessons as extended text and (ii) the fact that they are not embedded into the specific processes they intend to improve [64].
- IT solutions lend themselves to effectively managing explicit (codifiable) knowledge, whereas tacit knowledge is more appropriately spread by social methods. Databases alone are insufficient, attention must also be given to the human aspect [17][27][28, p. 315].
- Inhibitors to collecting and disseminating lessons learned include lack of time and opportunity, cost considerations, lack of management support, blame culture, and poor IT infrastructure [17, Ch. 6][27].
- Formal processes and procedures have been shown to improve project learning in organizations [17][27].

### 2.5.3 Learning from projects to improve PD processes

Research efforts to learn from projects for the specific application of improving PD processes—or i.e. realizing PD process feedback—have been reported in the literature.

Kim et al. [66] report on an empirical approach in a Korean electronics company that improved its macro-level PD process through an analysis of its PD project failure cases. Although these authors provide some insight into their procedure, it is not clear how failure cases were analyzed to identify causal factors to the outcomes of these projects. Subsequently, researchers addressed causes of failure by respectively assigning high-level tasks and evaluation criteria to phases and phase reviews. These authors demonstrate the utility of examining failure cases to inform improvements in existing company PD processes. However, the high-level root causes identified and equally superficial solutions, raises questions regarding the effectiveness of such an approach on a more complex development program.

Smith [18], a management consultant, proposes a 12-step process for organizations to continuously adapt and improve their PD processes. The process is defined as follows:

*Laying the foundation*
1) Name your improvement process carefully.
2) Piggyback on existing strengths.
3) Pick a reviewing pattern.

*Conducting reviews*
4) Assign a reviewer.
5) Constructively balance positive and negative findings.
6) Focus on an improved process.

*Collecting information*
7) Interview key participants.
8) Back up the interviews with data.
9) Measure progress with ongoing metrics.

*Closing the all-important feedback loop*
10) Establish a closure mechanism.

*Institutionalizing the process*
11) Review every project.
12) Align the process with corporate objectives.

Although the author offers pragmatic and practitioner-oriented advice, it is mostly anecdotal and absent of the scientific rigour typical of research articles. The proposed process serves as an experience-based framework, however, it is too high-level to be readily implementable and lacks practical guidance. This, coupled with the simplicity of the process, is foreseen to render its application problematic on complex development programs.

## 2.6 Discussion: Specifying the gap

What is missing from the literature is research into the ongoing improvement of generic PD processes after their initial implementation in organizations. More specifically, there is a lack of accessible techniques for undertaking the ongoing improvement of these processes.

The ongoing improvement of PD processes can be achieved through the concept of closed-loop feedback. It was identified as an important factor in converging underlying and generic PD processes and thus increasing the likelihood of successful implementation. Some closed-loop feedback techniques exist, however, they lack the practical guidance and rigour to be readily implemented and effective in organizations undertaking complex programs. The project learning literature confirms that most organizations are not leveraging their experiences from past projects in this way. This body of research, especially the work of Williams [30][31], brings visibility to the multifaceted difficulties with project learning on complex programs and identifies the need for more sophisticated project learning mechanisms dedicated to complex programs. This includes systematic means of untangling their non-intuitive behaviour and identifying root causes of outcomes.

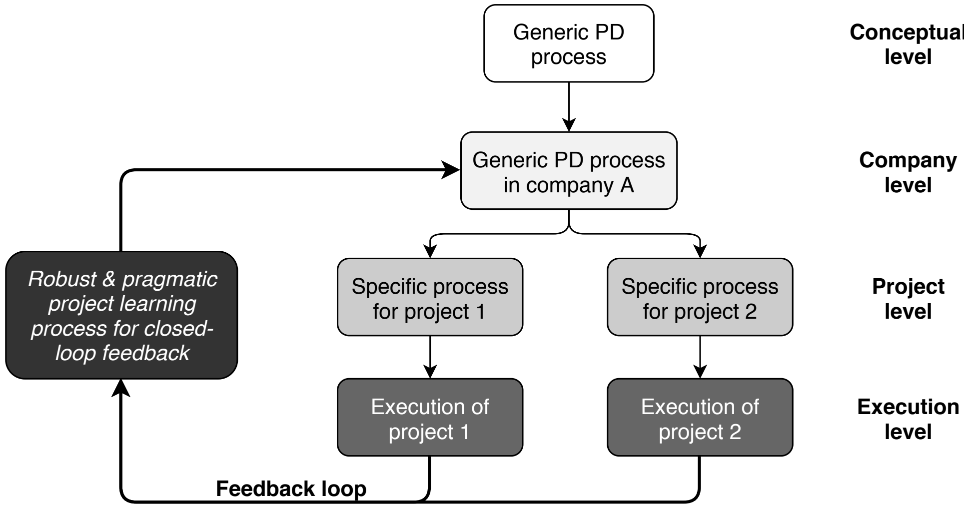


Figure 2.5: Gap in the research for a project learning process for realizing the closed-loop feedback of generic PD processes as a means of achieving their ongoing improvement.

The broader gap in the research is synthesized in Figure 2.5, which expands on Figure 2.4. Informed by the guidance outlined in Subsection 2.5.2, a full-fledged process for learning from complex programs to improve PD processes should be a practical and systematic means of (i) strategically collecting data, (ii) extracting non-obvious lessons, and (iii) addressing such lessons in generic PD processes. This research project *does not* intend to address this entire gap. Rather, it intends to make *a partial contribution* to this gap. Specifically, this work takes aim at the lower-level limitations with knowledge extraction from archived complex development programs, i.e., steps (i) and (ii) of the feedback loop. This research project is concerned with studying an archived development program for a complex product to uncover knowledge specific to the host organization's PD process. Of particular interest is untangling the program's non-intuitive behaviour and identifying the root causes of its outcome. Ultimately, this work seeks to enable to the broader gap in the research.

### 2.6.1 Synthesis

- The ongoing improvement of PD processes can be achieved through the concept of *closed-loop PD process feedback*, whereby organizations learn from experiences on past PD programs to improve generic PD processes.
- Although this concept is known, learning in this way does not seem to be particularly successful. Existing project learning techniques are overly simplistic and inadequate for organizations undertaking the development of complex products.
- The limitations of project learning are multifaceted, however, there is a recognized need for more sophisticated learning mechanisms capable of managing the complexity inherent to complex programs. This includes robust and systematic means of untangling their counter-intuitive behaviour and identifying root causes of outcomes.
- This research project intends to address the need for more sophisticated learning mechanisms *as an enabler to* realizing the closed-loop feedback of generic PD processes.

# Chapter 3

# Research design

*In the third chapter of this thesis*, the reader is provided with a description of the research design. This includes *what* was done to accomplish the research purpose, *how* it was done, and the rationale behind—i.e. *why*—this research design was chosen. Means for establishing quality and rigour throughout the design and execution of this study are also demonstrated.

## 3.1 Introduction

The case study was selected as the *strategy of inquiry* for gaining insight into and developing an explanation as to *why* aircraft development programs go over schedule in the context of a commercial manufacturer. The study was undertaken in the *context* of a multinational commercial aircraft manufacturing company—*AeroCo*—and centred on the single *main case* of a development program for a new aircraft model, the *Model I* program.[1] A mixed-methods *research design* leveraging both quantitative and qualitative data was developed and implemented as detailed in the following section.

This chapter is supplemented by Appendix A which is a review of qualitative research concepts and a discussion of this research design in light of those concepts. Given that the research design (paradigm, methodology, and methods) applied in this research project is atypical in the engineering research tradition, the aforementioned appendix was included for the interested reader.

## 3.2 Outline of the case study

The discrete research phases and activities comprising the case study are presented sequentially in Figure 3.1. The boldface text identifies the research phases and the white text boxes represent the research activities that comprise the phase. The looping arrows represent the iterative reality of some activities.

[1] Given the competitive nature of the aerospace industry, the decision was made at the outset of this research project to conceal the identity of the company and development program studied in this work. Measures were taken to not disclose any confidential information and thus findings are anonymised and dates or values are assigned a correction factor to protect identity without affecting the credibility and trustworthiness of the findings.

The sequence presented in Figure 3.1 serves as the organizing principle for the remainder of this chapter as each subsequent section corresponds to a phase.

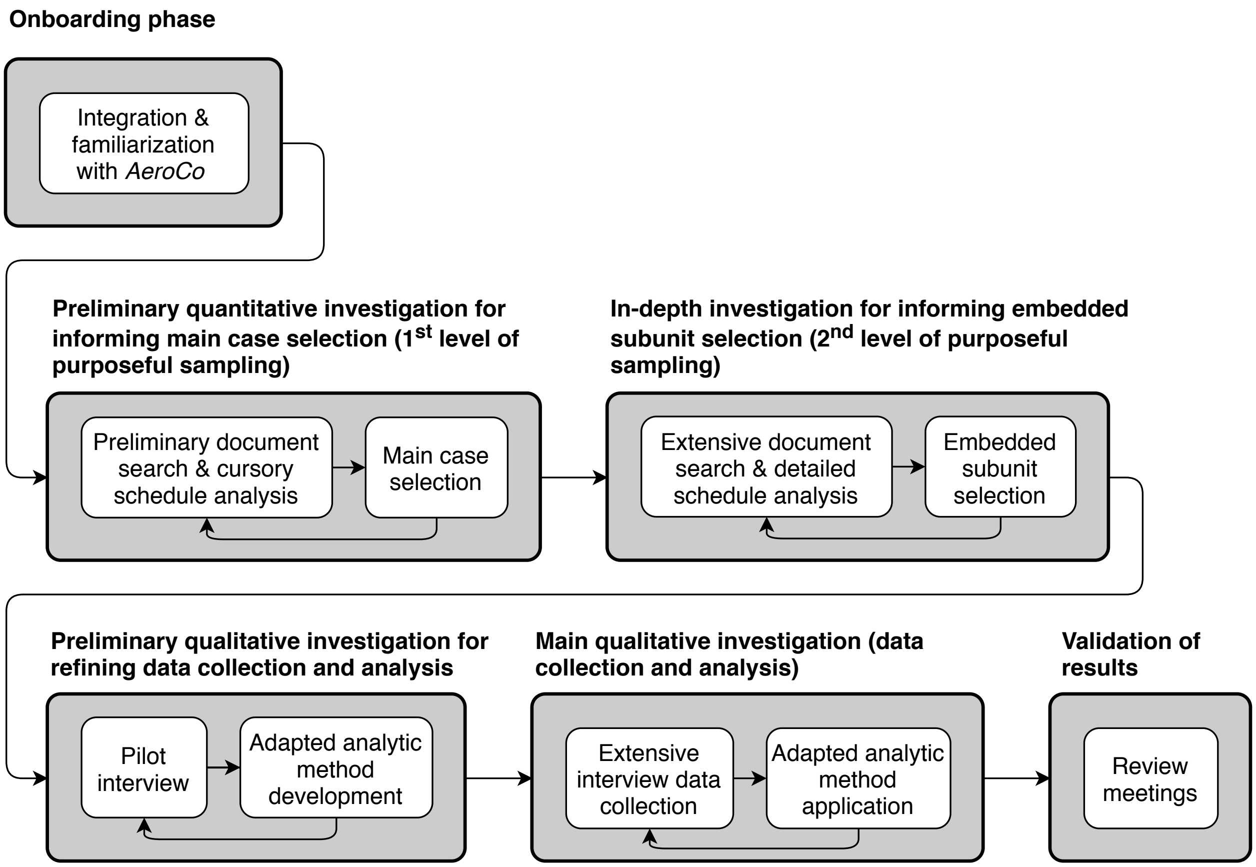


Figure 3.1: Outline of the sequential research activities comprising the study.

## 3.3 Integration and familiarization with the context of the study

The case study is fundamentally a form of *empirical inquiry* [67, p. 14] in that new understanding is developed through direct observation and experience of the phenomenon of interest [68]. As a preliminary to *this* case study, it was thus necessary for the researcher to develop a fundamental understanding of "how things worked" at *AeroCo* and get integrated into the culture of the organization. The researcher spent a preparatory 6 month period embedded with a cross-disciplinary team as a way to get immersed in the main case's context and acquainted with the technical, social, and organizational complexities of the organization.

## 3.4 Preliminary quantitative investigation for informing main case selection

After the onboarding phase, the case study was initiated with the selection of a newly completed development program in the organization's recent past—i.e. a main case—suitable for investigation. The main case—or "bounded system"—is the finite unit of analysis that establishes the boundaries of the study [69, pp. 40-3]. This first level of *purposeful sampling* is the subject of this subsection.

*Purposeful sampling* is a means of non-probabilistic sampling in qualitative research in which a sample to study is selected based on yielding the richest information relevant to the research purpose [69, pp. 76-8]. The phenomenon of interest—i.e. *why* aircraft development programs overrun their baseline schedules—and the greater purpose of this study—i.e. to support generic PD process improvement—drove a three-fold criteria that was used to discern the most appropriate case for study. First, the case needed to exhibit a significant degree of schedule overrun such that the phenomenon of interest could be observed. Second, the case needed to have an extensive scope as more of the organization's underlying product development (PD) process would be encapsulated. Third, the case needed to be relatively recent in the organization's past as to ensure sufficient data in the form of interviews and archived documents.

Given that aircraft development programs are infrequently undertaken by aircraft manufacturing organizations, the prospective program pool was limited. Nonetheless, a preliminary quantitative analysis using data from archived program documentation was conducted to inform the selection.

### 3.4.1 Preliminary document search and cursory schedule analysis

It was common knowledge at *AeroCo* that delivery of the *Model I* was late and that most major development programs in recent years had followed a similar trend. In order to ascertain this claim regarding the *Model I* development program and assess the first criteria of main case selection, it was necessary to determine the overall degree of schedule overrun experienced by the program. To this end, a preliminary document search and schedule analysis were conducted.

The purpose of the retrospective schedule analysis was to recreate the program's *as-planned* and *as-executed* timelines such that schedule overrun/deviation could be determined through comparison. In this application, "development" was considered as the period of time starting with the *official program go-ahead* milestone and ending with the *type certification* milestone, which is generally closely followed by first delivery. Timelines were recreated using dates extracted from documents produced over the duration of the development program. The *as-planned* timeline was generated from recovered schedules that were part of the program's planning. Actual dates for the milestones in the *as-executed* timeline were found by referring to the aircraft's type certificate and through a cursory search of the program's document repositories. This also served to scope the breadth of existing program documentation.

### 3.4.2 Main case selection

The results of the preliminary schedule analysis are presented in Figure 3.2. At the outset of the program, development was planned to take *32 months* and in reality it was determined to have actually taken *58 months*. The significant disparity between the *as-planned* and *as-executed* timelines was an indicator that more in-depth investigation was needed into the development program.

The *Model I* development program was selected as the main case for in-depth examination as it best fit the purpose and constraints of this study. The development was found to have been approximately 2 years late (criteria 1), the scope of this specific case was a comprehensive clean

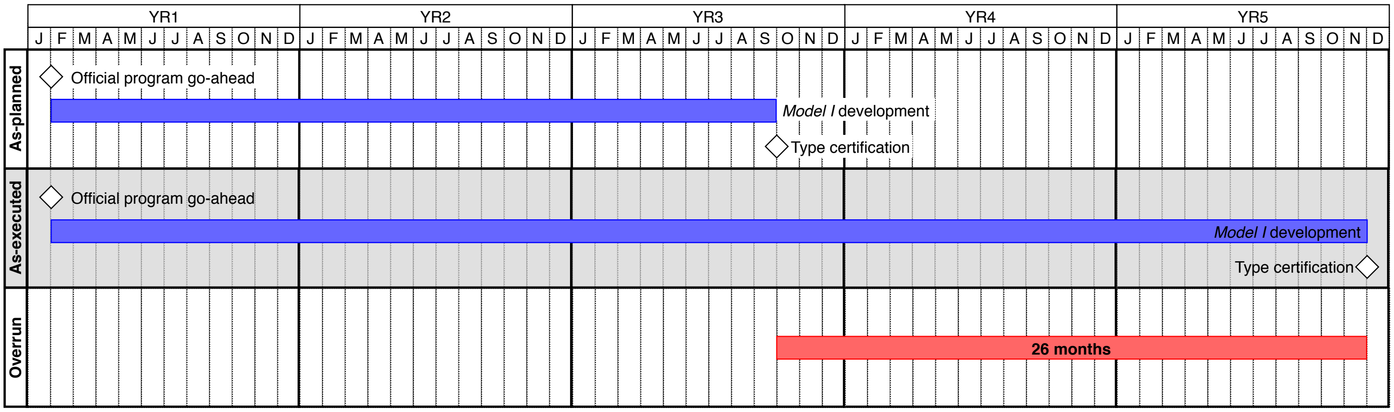


Figure 3.2: Preliminary retrospective schedule analysis comparing *as-planned* and *as-executed* timelines to quantify schedule overrun for the overall program.

sheet development and thus covered the organization's entire underlying PD process (criteria 2), and the program occurred less than 15 years ago (criteria 3). An additional convenience factor taken into consideration was that former team members deployed to this specific program would be on site and available for meeting in person.

Given the breadth of the "bounded system" that the *Model I* development program represents, it was necessary to further narrow the focus of the investigation. This is the subject of the following section.

## 3.5 In-depth investigation for informing embedded subunit selection

Selection of the *Model I* effectively set the boundary of study, however investigating the entirety of this development program in the setting of a single Master's research project was beyond scope. A second level of purposeful sampling was necessary for disagregating the main case into less extensive elements—denoted as *subunits of analysis*—such that insight into the original phenomenon of interest could be gained from studying them [69, pp. 80-2]. For this application, that meant breaking down the development of the *Model I* such that insight into the macro-level schedule overrun could be gained by examining more manageable elements comprising the greater program. Research methodologist Yin [67, pp. 46-53] terms this type of case study design a *single-case embedded design* as subunits of analysis are embedded within the main case.

The techniques described in Sub-subsection 3.4.1 were extended for this subsequent level of purposeful sampling.

### 3.5.1 Extensive document search and detailed schedule analysis

An extensive document search and detailed schedule analysis were undertaken as a strategic means of decomposing the overall program into subunits and informing the selection of which to study. In a more systematic application of these techniques, the researcher further detailed the *as-planned* and *as-executed* timelines of Figure 3.2 as to depict them at a finer resolution. This involved three broad steps, which are further described in the paragraphs to follow:

(1) selecting a recovered program schedule for the *as-planned* timeline,
(2) recreating the *as-planned* timeline with actual dates to yield the *as-executed* timeline,
(3) comparing *as-planned* and *as-executed* timelines to quantify schedule overrun/deviation.

**(1)** In searching through archived planning material for the *Model I* several types and iterations of schedules were found. With the intention of recreating a schedule using actual dates, one was selected for the *as-planned* timeline to serve as a model (or template) for the following step. A recovered top-level version of the integrated master schedule (IMS) used as part of the program's proposal was chosen. This top-level schedule consisted of approximately 30 line items which included major phases/activities and events such as gates and various milestones. This was an ideal choice as it (i) represented the program's critical path at a manageable level of detail and (ii) was an early forecast of development. With respect to point (ii), this baseline development schedule provided insight into the organization's latent understanding of its own PD processes and corresponding estimated performance in executing them.

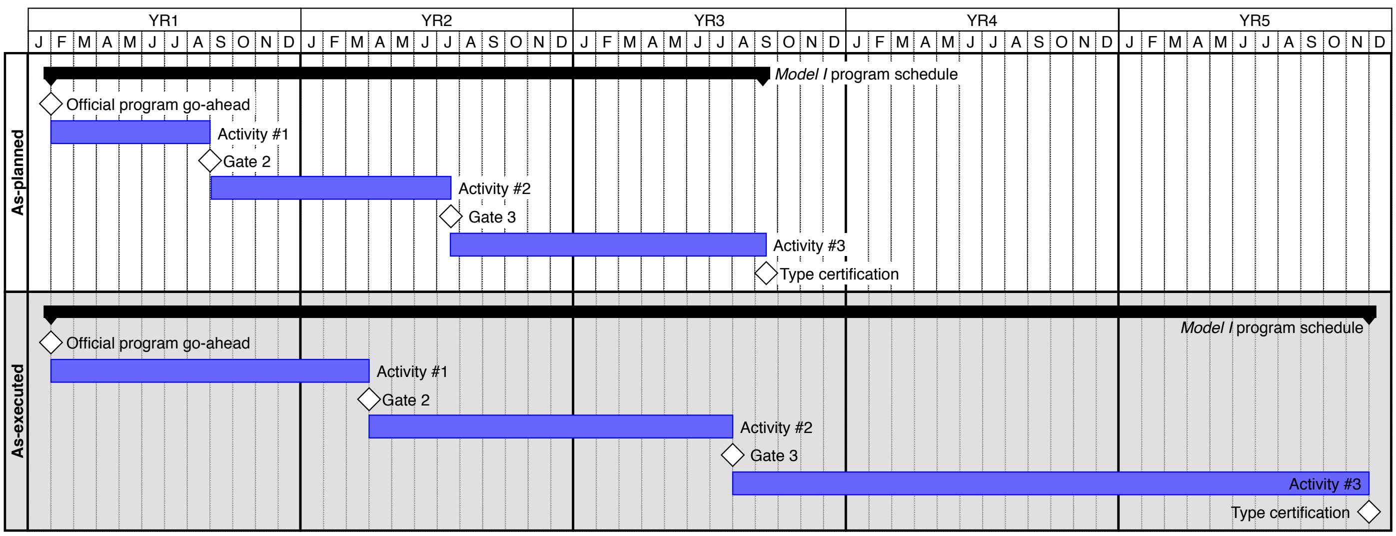


Figure 3.3: Partial detailed schedule analysis comparing *as-planned* and *as-executed* timelines.

**(2 & 3)** With the *as-planned* timeline defined, it was necessary to recreate the *as-executed* timeline using dates of phases/activities and events as they actually occurred. The concept is highlighted in Figure 3.3 which is a partial illustration of the detailed schedule analysis showing 7 line items. Historical timeline data was extracted from *documents* generated over the development of the *Model I*. Preliminary document searches from the main case selection showed an overwhelming amount of material pertaining to almost every functional area of the aircraft's development.

A strategic approach was taken to searching through this material and extracting data. First, a search for documents that periodically reviewed the progress of the overall program and sub-teams was undertaken. This first pass was for indiscriminately populating the *as-executed* timeline by extracting actual dates of events as per the line items of the *as-planned* timeline. Examples of events include successfully passing gates, completion/delivery of prototype assemblies, first flight, and successful certification tests. Gates and milestones were especially important in delineating the start and end of program phases/activities.

Subsequently, a second more precise document search was conducted specifically targeting material pertaining to areas lacking detail. Once sufficiently defined, it was possible to identify individual phases/activities of the development that did not perform as expected by quantifying their degree of schedule overrun. Ultimately, two program phases/activities were selected as the embedded subunits of analysis, denoted as *Activity #1* and *Activity #2*. This selection, detailed in the following Subsection 3.5.2, served to limit the boundaries of a third and final document search and analysis.

This final search was narrow but exhaustive, seeking material strictly pertaining to the two selected subunits. This involved reading through documents in search of:

(i) *historical dates* for improving the accuracy of the subunits' *as-executed* timelines,
(ii) *former program team members* deployed to these activities for identifying interview candidates, and
(iii) *additional evidence of interest* for corroborating emerging findings.

With respect to point (ii), a list of contacts and their associated positions in the program's organizational hierarchy was developed in preparation for the subsequent research phase. With respect to point (iii), some documents contained evidence of complications as they were affecting the program in real time. This information served to corroborate the findings from the retrospective schedule analysis, a concept known in qualitative research as "triangulation" [69, pp. 215-6].

#### 3.5.1.1 *Documents* as a data source

In searching through archived program documentation, an array of documents were encountered and examined, including:

- *Program management material,* for example, presentations from (i) gate reviews and technical audits and (ii) recurring program status meetings. These documents provided high-level overview of the program's progress from the perspective of the entire program or individual subteams, bringing visibility to major events/milestones and reporting generally on program health.
- *Engineering drawings and specifications,* for example, first issues and revisions of drawings/CAD models for prototype and production aircraft. These documents provided the data necessary to trace the evolution of the aircraft's design over time.
- *Supplier tracking logs and correspondence.* These documents provided data giving insight into the progression of prototype aircraft assembly.
- *Certification/regulatory material,* for example, reports, memos, transmittals, and issuances. These documents were of particular importance to the researcher as their officiality brought confidence to the *authenticity* of the data they contained. They provided data pertaining to the program's progression through many regulatory checkpoints on the path to type certification.

In the context of qualitative research these documents are considered *primary sources.*

#### 3.5.1.2 Synthesis

Iterative document searches were *primarily* undertaken to extract historical timeline data for the detailed retrospective schedule analysis. *Secondarily*, this activity served to (i) identify interview candidates for the subsequent qualitative data collection phase and (ii) corroborate the findings of the schedule analysis. Ultimately, it was noted that the documents generated over the course of a development program contained a wealth of data pertaining to the PD process and represented a considerable knowledge asset to the greater organization. For the researcher, examining archived documents had the added benefit of learning the intricacies of the *Model I*'s development and gaining special insight into this important narrative in the organization's history. This was instrumental in performing effective and substantive interviews as the researcher was more readily able to engage in constructive discussion and understand interviewee perspectives.

### 3.5.2 Embedded subunit selection

The second level of purposeful sampling resulted in the selection of two subunits embedded within the main case: *Activity #1* and *#2*. Both correspond to major phases/activities part of an aircraft's development, the former design-related and the latter testing-related. The decision to select these two specific subunits was driven by two findings from the extensive document search and analysis. *First*, was uncovering the presence of schedule overrun/deviation on both activities. *Second*, was uncovering additional evidence that difficulties were encountered in the execution of these activities. For *Activity #1*, the presence of unplanned rework was discovered. For *Activity #2*, recovered documents noted issues affecting the activity as it was actually being undertaken. Based on these findings, *Activity #1* and *#2* were well suited for further investigation as both subunits seemed *information-rich*.

## 3.6 Preliminary qualitative investigation for refining data collection and analysis

The previous phases of the case study established that the selected main case was over schedule as were the embedded subunits. From this point forward qualitative data would be leveraged to develop an understanding and explanation of *why* the development program experienced schedule overrun. This subsection outlines the phase dedicated to researching, practising, and refining qualitative data collection and analysis methods.

### 3.6.1 The research interview and pilot application

The *research interview* was chosen as the method to elicit qualitative data from former program team members. Interviews would give respondents the opportunity to share their perspectives on the factors that caused the development to go over schedule from the unique positions they occupied on the program. This was the most viable mode of data collection given that (i) the development of the *Model I* was a historical event and could not be directly observed and (ii) archived documents were impractical for this end.

The interview format used for this study was *semistructured* such that interactions were guided by a list of questions to gather specific information but were also flexible in the flow of discussion [69, Ch. 5]. Informed by the researcher's experiences in the previous phase, a list of questions—denoted as the *interview guide*—was developed. As a means to refine the guide and practice conducting interviews, a series of *pilot interviews* were held with a single former program team member over multiple sessions. The selected respondent had been directly involved on *Activity #2* and was an individual with whom the researcher had good rapport. Pilot interviews were for verifying that questions yielded the desired type of data and were conveyed in a way that was easily understandable.

A genericized version of the interview guide is presented in Table 3.1. The guide was comprised of three initial *closed-ended* questions regarding the professional background of respondents. These served to situate the respondent's perspective from which they experienced the program and to collect data common to each respondent. The remaining seven questions were *open-ended* and purposefully broad as to encourage the collection of descriptive and meaningful data. Questions 4 and 5 were intended for extracting data pertaining to the causal factors driving schedule overrun at the program level. Questions 6 was intended for refocusing the same line of inquiry but at the level of the subunit of analysis.

Table 3.1: Interview guide.

| Order | Question |
|---|---|
| 1. | In what capacity were you involved on the *Model I* development program? |
| 2. | Were you deployed on the program from the beginning to end? |
| 3. | Was this your first major development program or did you have experience on any others? |
| 4. | From our investigation we found the Model I development took roughly twice as long as scheduled. From your understanding, why was that the case? |
| 5. | What are typical problems that arise throughout the development process that stall a program/put it on hold? |
| 6. | Were there any major sources of delay on the activity that you were directly deployed to? |
| 7. | Was the planned baseline schedule for the activity/program in general realistic? |
| 8. | How can schedule overrun on this activity/program in general be avoided in the future? |
| 9. | On the *Model I* development program, were there any aspects that went particularly well that should be repeated in the future? |
| 10. | What are your thoughts on *AeroCo's* generic gated development process? |

Question 7 was an addition informed by the pilot interview to further explore a recurring idea in the context of *AeroCo*: that projects/programs are late because of an overaggressive scheduling culture. Questions 8, 9, and 10 reflect the greater motivation of the case study which was to support the improvement of the organization's generic PD process framework. Where questions 4 to 7 were for gathering data pertaining to *negative* causal factors that contributed to the program going over schedule, questions 8 and 9 were for gathering *positive* causal factors enhancing the program. Lastly, question 10 was intended for getting insight into, and gauging the employee base's attitude towards, the organization's generic PD process framework.

### 3.6.2 Adapted analytic method development

There are diverse methods for analyzing qualitative data published in the academic qualitative research literature. Some examples of these methods traditional to the *social sciences* [70] include grounded theory (GT) and thematic analysis (TA) emerging respectively from the disciplines of sociology and psychology. The specific method implemented in this study was an adapted form of *thematic analysis* augmented using additional data reduction and display techniques.

This subsection briefly lays out the established methods and techniques taken from the literature from which the researcher's actual analytic method was adapted.

#### 3.6.2.1 Overview of qualitative data analysis

Miles and Huberman's view of qualitative analysis—as three concurrent and "interwoven" activities: *data reduction*, *data display*, and *conclusion drawing/verification* [71, pp. 10-12]—informed the development of the adapted analytic method. As recommended by these authors, special consideration was given to displaying emerging results in "immediately accessible, compact form[s]". The qualitative data collected in this study was in the form of *words*, i.e. *extended text*. For the researcher, the most striking differences in using qualitative data as opposed to quantitative, included (i) the laboriousness of processing extended text and (ii) the methodological flexibility afforded by qualitative research methods.

#### 3.6.2.2 Thematic analysis

*Thematic analysis*, abbreviated as TA, is the fundamental basis of the analytic procedure applied in this study. Of the different variations of the method, Braun and Clarke's "reflexive TA" [72][73][74] was selected. These authors define it as a method for identifying, analyzing and reporting patterns—called *themes*—across qualitative datasets. *Themes* embody "something important about the data in relation to the research question, and represent[ ] some level of *patterned* response or meaning within the dataset" [72, p. 82]. *Reflexive TA* is distinguished from other varations by "emphasiz[ing] the active role of the researcher in the knowledge production process" [74, p. 6]. The references cited above outline the six-phase analytic procedure put forth by these principal TA authors.

Consistent with the paradigmatic underpinnings of this study, the researcher selected this method based on its flexibility, simplicity, and practicality. Braun and Clarke note that TA "offer[s] a more accessible form of analysis, particularly for those early in a qualitative research career" [72, p. 81].

#### 3.6.2.3 Qualitative content analysis

*Qualitative content analysis*—abbreviated as QCA—was drawn on to complement Braun and Clarke's TA procedure. QCA is also a method for analyzing patterns across qualitative datasets and shares a degree of commonality with TA [74, p. 2]. Authors Vaismoradi et al. delineate the subtle differences between TA and QCA in reference [75]. *Data reduction/condensing techniques* put forth by QCA methodologists Schilling [76, pp. 30-2] and Mayring [77, pp. 63-87] were of specific interest to the researcher. Mayring's work was especially insightful for outlining data reduction procedures that were clear, easily understandable, and readily reproducible.

#### 3.6.2.4 Thematic networks

*Thematic networks*—abbreviated as TN's—are a data display technique formalized by Attride-Stirling to augment TA's by assisting theme development and visually representing analytic results as "web-like illustrations (networks)" [78, p. 386]. TN's offered a robust means for (i) systematically abstracting higher-order themes from lower-order themes and (ii) depicting relationships between different levels of themes. For the *researcher* it was a tool for aiding interpretative analysis (data reduction) and for the *reader* it was a way for easily communicating analysis results (data display). The generic model of a TN is presented in Figure 3.4. The terminology used in this thesis for referring to the varying levels of abstraction among developed themes, “first-”, “second-”, and “third-order”, were inspired from reference [79].

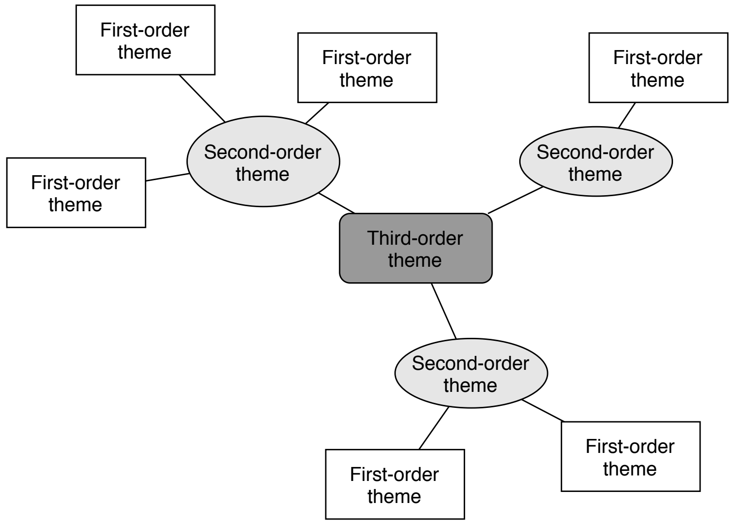


Figure 3.4: Generic model of a thematic network, adapted from reference [78, p. 388].

#### 3.6.2.5 Causal maps

*Causal maps*—alternatively called *causal networks*—are a data display method common in qualitative research for conceptualizing and illustrating the dynamics of complex situations [80]. Although Braun and Clarke integrate *maps* into their TA procedure, the researcher opted for an alternate variation from Miles and Huberman [71, Ch. 6, 8]. This specific variation was slightly more elaborate and thus communicated more information while still being practical. Causal network diagrams were used to illustrate *themes* and *cause-and-effect relationships* shared between them. Relationships are represented using *arrows*, such that the tail of an arrow leaves from a *cause* and points in the direction of an *effect*. Causal relationships could be either *positive* or *negative* as indicated by plus signs (+) and minus signs (–), respectively. Where positive relationships *increase* a given effect, negative ones *diminish* them. An excerpt of a causal map developed as part of an intermediate cross-case analysis is provided as an example in Figure 3.5.

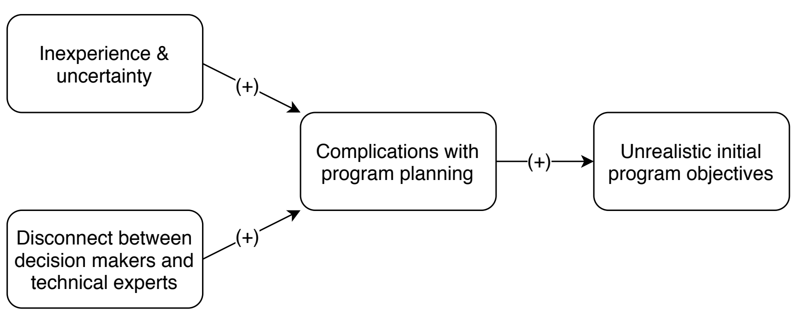


Figure 3.5: Excerpt of a causal map from intermediate cross-case analysis 2.

Notably, efforts to apply this method to gain insight into the dynamic of complex development projects were reported in the literature [30][31][81].

#### 3.6.2.6 Synthesis

The method used for analyzing qualitative data in this study was an adapted form of *thematic analysis* (TA) augmented using supplemental data reduction techniques from *qualitative content analysis* (QCA) and data display methods of *thematic networks* (TNs) and *causal maps*.

## 3.7 Main qualitative investigation

With the boundaries of the case study set and qualitative methods established, the main data collection and analysis phase was initiated. The following subsections respectively outline each research activity.

### 3.7.1 Extensive interview data collection

The in-depth investigation conducted to inform the selection of embedded subunits *Activity #1* and *#2*, as described in section 3.5, was also used for generating a list of former program team members who worked on each activity. The researcher's objective was to speak with as many former program team members as possible from all levels of the organizational hierarchy still accessible for interview.

Interview meetings were mostly held in person, and limited to an hour in length. Rather than recording interview audio as is typical with this method of data collection, the researcher opted for *non-verbatim transcription*, i.e. rigorous note-taking. The justification for this decision was driven by the nature of individual accountability on projects. Elements of *blame culture* or *fingerpointing* may pervade organizations whereby mistakes or poor project performance negatively impact individual careers [82][83]. Thus, avoiding the uneasiness caused by recording devices and enabling respondents to anonymously "speak off the record" was thought to allow for unrestricted and richer accounts of individual experiences on the program. Additionally, the researcher emphasized this exercise's intention as a learning activity as opposed to an audit in an attempt to further promote uninhibited discussion.

A colleague was enlisted to serve as stenographer while the primary researcher directed the interview. After each interview, the researcher and stenographer would debrief and review the transcript together. If parts of the transcript were unclear or particular questions were only sparingly detailed, respondents were contacted for follow-up either through informal consultation or telephone call. After each interview, a *case-based memo* was generated by the researcher as a mechanism for reflecting on what was learned from the interaction and capturing general impressions [84]. This concept was taken from the grounded theory literature [85][86] as a means for re-situating the researcher later during the analysis portion. The reader is referred to Appendix B for an example of a case-based memo.

In total, 20 former program team members were interviewed and 7 additional individuals were consulted but never officially questioned. A list of interviewees is provided in Table 3.2. The original scope of data collection was limited to individuals active on the selected subunits of analysis, however the researcher decided to go beyond these bounds and collect data from individuals active on other aspects of the program. This was driven by the encouragement from respondents to seek out specific individuals who filled unique roles on the program and would be in a good position to share insightful perspectives. Ultimately, personnel from 6 functional areas of aircraft development were surveyed as indicated in the second column of the Table 3.2.

Table 3.2: Summary of former program team members interviewed as part of qualitative data collection.

| **Case[2] identifier** | **Development activity deployed to** | **Position occupied on the *Model I* program** | **Current position** |
|---|---|---|---|
| C1 | Activity #2 | Engineer | Middle manager |
| C2 | Activity #2 | Middle Manager | Senior Manager |
| C3 | Activity #2 | Engineer | Engineer |
| C4 | Activity #2 | Engineer | Engineer |
| C5 | Activity #2 | Engineer | Engineer |
| C6 | Other #1 | Specialist | Specialist |
| C7 | Other #1 | Specialist | Specialist |
| C8 | Activity #1 | Middle manager | Middle manager |
| C9 | Activity #1 | Engineer | Middle manager |
| C10 | Activity #1 | Engineer | Engineer |
| C11 | Activity #1 | Middle manager | Middle manager |
| C12 | Activity #1 | Middle manager | Middle manager |
| C13 | Activity #1 | Engineer | Middle manager |
| C14 | Activity #1 | Engineer | Engineer |
| C15 | Other #2 | Engineer | Engineer |
| C16 | Other #2 | Engineer | Engineer |
| C17 | Other #2 | Engineer | Engineer |
| C18 | Other #3 | Middle manager | Senior manager |
| C19 | Other #3 | Engineer | Engineer |
| C20 | Other #4 | Engineer | Engineer |

#### 3.7.1.1 General observations from conducting interviews

Some general observations were noted based on the researcher's experiences interviewing former program team members:

(1) For a considerable number of respondents, it became evident that they had never been debriefed before regarding their experiences on the program.
(2) In speaking to their experiences, a considerable number of respondents had an easier time identifying successes and failures by comparing different programs they had worked on, as opposed to identifying successes and failures within the scope of the single program. This contributed to contradictions in the dataset and ultimately some conflicting findings.
(3) Not all respondents were able to provide the same level of insight into the inner workings of the program. Individuals occupying management positions had comparatively rich and nuanced responses as opposed to front-line practitioners.
(4) Lastly, some respondents tended to focus their accounts of the development on how it *should* have been done as opposed to how it *actually* occurred in reality. This data was not

[2] The term "case" is used here to refer to respondents and not the main case.

useful for identifying fundamental success and failures affecting the development program of the *Model I*.

### 3.7.2 Adapted analytic method application

The resulting qualitative data yielded by the interviews consisted of 20 transcripts ranging in length from 4 to 8 pages of text each. Ultimately, 6 transcripts were selected from this qualitative data pool for subsequent analysis. The researcher's selection of these specific transcripts was motivated by prioritizing the analysis of the most substantive transcripts in the limits of available time. Table 3.2 shows the interviews selected for analysis as indicated by the greyed-out rows. These interview transcripts—denoted hereafter as cases—composed the downselected *qualitative dataset* considered for analysis. In total, the qualitative dataset comprised 35 pages of extended text, counting approximately 23 500 words.

The remainder of this subsection lays out the integration and application of analysis and display methods for extracting findings from this dataset. The adapted analytic method followed a two-part application. First, for the *within-case* analysis, the researcher individually analyzed each case in its own independent context. Then, for the *cross-case* analysis, the researcher analyzed cases in context to one another. The two following sub-subsections respectively present the former and the latter.

#### 3.7.2.1 Within-case analysis

The within-case analytic procedure was used to develop *preliminary* or *candidate themes* from individual transcripts. The operational order for within-case analysis was such that the procedure was entirely applied to each transcript consecutively. Table 3.3 outlines the phases comprising the within-case analysis.

Table 3.3: Phases of within-case analysis.

| Phase | Description |
|---|---|
| 1. | Establishing the configuration and parameters of the analysis. |
| 2. | Transcript checking, familiarization, and segmenting. |
| 3. | Coding: Paraphrasing and generalizing. |
| 4. | Within-case thematizing: Searching for and refining candidate themes. |

**Establishing the configuration and parameters of the qualitative analysis**

Given the methodological flexibility of qualitative methods, the researcher initiated the analytic process by configuring and establishing the parameters of the analysis to fit the specific application. The configuration of thematic analysis (TA) applied in this study was (i) *inductive* and (ii) focused mostly at the *semantic* level of meaning. First, with an *inductive* or *bottom-up* approach, findings are grounded in the data and the researcher avoids engaging with theory as to not impose preconceptions on emerging results [72, pp. 83-4][86, p. 11, 38]. This approach is also sometimes referred to as *data-driven*. Second, with a *semantic* or *explicit* approach, analysis is focused at the "surface-level" meaning of the data and does not go beyond respondent language [72, pp. 84-5][74, p. 11].

As a means to focus the analysis, the researcher specified the "selection criterion" and "level of abstraction" as proposed by Mayring [77, pp. 79-87]. First, the *selection criterion* defines the relevant material for analysis as per the research interest. Data fitting the definition is considered and that which does not is omitted. As the research interest was to understand the causal factors of overrun with the intention of improving company-level PD processes, the selection criterion was broadly defined as material describing positive or negative influences affecting the program in achieving its objectives of schedule, cost, and quality. Second, the *level of abstraction* defines the specificity or generality of the final themes. For this application, it was defined as concrete causal factors connected with positive or negative outcomes generically applicable across different programs.

Lastly, the researcher specified a final set of three parameters denoted the "content-analytical units" as proposed by Mayring [77, pp. 51-3]. These served as a guide for the analyst[3] to disaggregate the entire raw dataset in a way that was consistent and uniform. The three content-analytical units are described and correspondingly defined below.

(1) The *coding unit* is the minimum amount of textual data to be coded and is described as the "sensitivity" of the analysis. For this application, it was every complete statement.
(2) The *context unit* is the amount of textual data needed for making a coding decision. For this application, it was every section of text unified by a common topic.
(3) The *recording unit* is the portion of text for which the themes are representative. For within-case analysis this unit was each singular interview transcript and for the cross-case analysis this unit was the entire dataset.

**Transcript checking, familiarization, and segmenting**

As a preliminary to each within-case analysis, the researcher prepared by checking the transcript and becoming reacquainted with the specific case under examination. Transcripts were looked over to (i) correct spelling mistakes and formatting issues, (ii) remove repeated portions of data, and (iii) consolidate any supplemental notes. At the same time, proofreading transcripts was a means for the researcher to get refamiliarized with the content or as put in reference [73, p. 87-8] "immersed" in the data. Referring to the transcript's corresponding case-based memo in this phase was also helpful for putting the researcher back into the context of the interview and for recalling some defining characteristics of the exchange.

A paper-based approach was taken for the following activities in this phase. First, content not pertinent to the selection criteria was identified for omission from analysis. It mainly included (i) digressions to irrelevant topics and (ii) material generated from questions in the interview guide (Q1-3 & Q10) not directly relevant to this aspect of the study. Next, transcripts were segmented by splitting them into context-units and then further splitting each context-unit into coding-units. These activities were iterative in nature and required reading through each transcript several times thus serving to further reinforce the researcher's "immersion" in the data. Impertinent content, context units and coding units were all demarcated using colour-coded highlights.

**Coding: Paraphrasing and generalizing**

With the transcript segmented and trimmed of impertinent data, the researcher started the

[3] In this study, the researcher and the analyst were the same individual.

*coding* process. Coding is a data reduction technique common in qualitative analysis for assign labels—called *codes*—to pieces of data [71, pp. 55-69][72, pp. 88-9][86, Ch. 3]. Codes are an intermediate product of the analytic procedure and the precursors to themes, closer to the data and less abstract. The inductive (data-driven) and semantic (explicit) configuration of this analysis meant the researcher developed an unlimited number of codes drawn directly from the data and focused mainly at its face value meaning. The researcher made use of a mechanistic style of coding proposed by Mayring [77, p. 65-87] that was well suited to this configuration and especially simple and effective.

Mayring's *paraphrasing* and *generalizing* "macro-operators" were applied for reducing a transcript's volume of data while preserving its core content. First, the *paraphrasing* macro-operator was applied for removing "non-content bearing" portions of the base material and for rephrasing the remaining text into an "abbreviated" and "uniform style". Each coding unit was systematically worked through and consequently reduced to initial codes, alternatively called *paraphrases*. Next, the *generalizing* macro-operator was applied to attain a subsequent level of reduction. Note that this macro-operator was only applied when required. It involved interpreting the meaning of paraphrases as to *broaden* their *level of abstraction*. The intent was to develop a selected paraphrase into a more general version of itself whereby the resulting generalized code implies the paraphrase.

The coding conducted in this phase aimed to stay true to the raw data. Codes were developed liberally and retained original respondent language when possible. Duplicate or closely related codes were not combined nor cut. The researcher noticed that the style of codes generated in this process varied according to the transcripts. Some respondents communicated using metaphors and stories which necessitated a greater degree of generalizing and resulted in longer and more complex codes. Other respondents communicated in a way that was straightforward and explicit which yielded a greater number of shorter codes. As a means to validate the coding process, the researcher met with an independent and unbiased colleague to compare the codes each party developed. Moreover, at several instances, the researcher presented coding results to the research group as a check of their accuracy.

Specific software tools exist to support coding and qualitative analysis more generally, however, the researcher opted for a manual approach using spreadsheets. This was more effortful and less economic but afforded the researcher an intimate role in the analysis. For each case, coding units were imported into a dedicated spreadsheet and every step in their analysis was documented. For this phase specifically, the transformation of *data extracts* into *paraphrases* and then into *codes* was recorded. Maintaining traceability of the analysis at every step was imperative for subsequent phases of the method. Before moving to the next phase, the researcher checked the set of finalized codes against their raw data extracts to verify that they were representative of the base material.

The reader is referred to Appendix B for an example demonstrating how the researcher coded data extracts. Moreover, as a means to put into perspective the effectiveness of coding as a data reduction technique, Case 2 is referred to as a typical example. The interview yielded a transcript counting 6078 words that was then segmented into 37 coding units that were then processed into 46 final codes counting 612 words. In terms of word count, coding served to condense the volume of data in this example by roughly 89.9 %.

**Within-case thematizing: Searching for and refining candidate themes**

Within-case thematizing was the phase dedicated to developing preliminary/candidate themes—the final and most abstract products of the within-case analysis—from the set of codes developed in the previous phase. Moving from codes to preliminary themes continued data reduction with another round of interpretative analysis refocused at yet a broader and more abstract level [72, pp. 88-9]. For each case, the process first began with rereading the set of codes and arranging them into groups according to their *shared meaning*. This step marked a shift in how codes were ordered, moving *from* their sequential position in the dataset *to* coherent groups unified by the idea they conveyed.

After forming groups of codes, the researcher developed themes by identifying the shared meaning or "implicit topic" [87, p. 101] underlying the code(s). Identifying themes included developing (i) a working title and (ii) a brief description of the "meaning-based pattern" [74, p. 4, 14] captured by the theme. As themes were deduced, the researcher concurrently categorized them according to level of abstraction. Content-related themes were categorized by nesting more specific themes under those with broader meanings. Three levels of abstraction were differentiated among candidate themes: main themes, sub-themes, and sub-sub-themes. For each case, as the analyst worked through the thematizing process a causal map was also developed.

The thematizing process is summarized in Figure 3.6 wherein the boldface text indicates the outputs of this phase: (i) a set of candidate themes and (ii) a corresponding causal map. Lastly, continuing the example of Case 2 presented in the previous phase, the analyst processed the 46 final codes into 16 main themes, 20 sub-themes, and 7 sub-sub-themes. Moreover, 4 separate revisions of the corresponding causal map were formulated to achieve an acceptable and final version. These outputs from the within-case thematizing phase for Case 2 are presented in Appendix B.

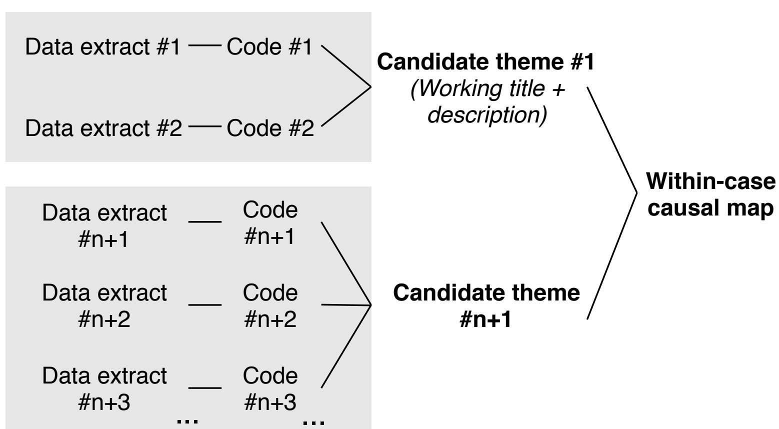


Figure 3.6: Summary of within-case thematizing phase.

#### 3.7.2.2 Cross-case analysis

Once individual cases were analyzed and candidate themes and causal maps were sufficiently representative of the boundaries of each case, the scope of the analysis was widened. Boundaries for this second portion of the analysis were broadened to encompass all individual cases and the *recording unit* defined in the first phase was adjusted accordingly. Cross-case analysis continued the thematizing process such that all candidate themes and causal maps developed independently for individual cases were juxtaposed and considered in relation to each other to further develop higher-order themes representative of the entire dataset.

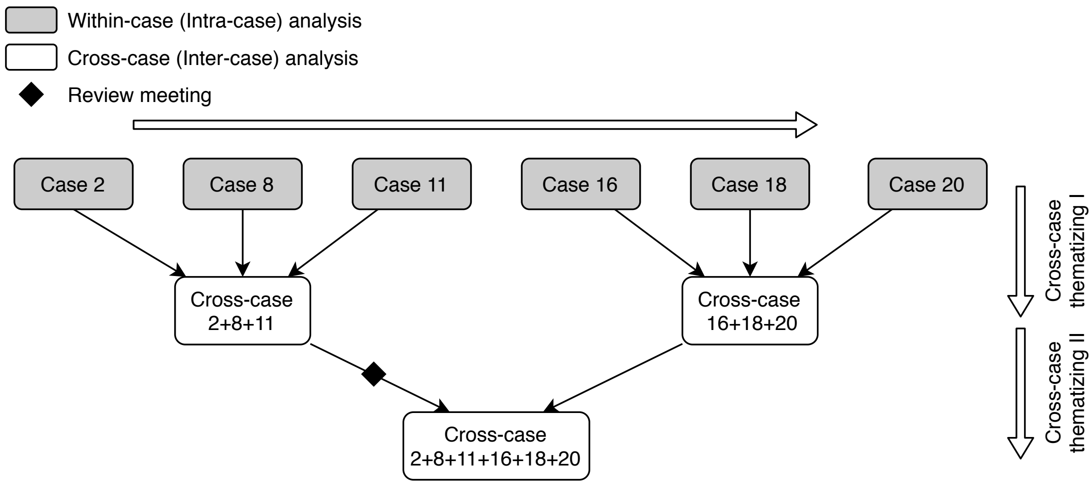


Figure 3.7: Within-case and cross-case analysis order.

Given that simultaneously analyzing all 6 cases was found to be too data-intensive, the researcher split cross-case theme development into two levels. The first level was for separately processing three cases at a time. The second level was for then processing the outputs from these two intermediate cross-case analyses in a final cross-case analysis. The order in which both within-case and cross-case analyses were undertaken is illustrated in Figure 3.7. Additionally, Table 3.4 outlines the phases comprising the cross-case analysis.

Table 3.4: Phases of cross-case analysis.

| Phase | Description |
| --- | --- |
| 1. | Cross-case thematizing I: Intermediate analyses |
| 2. | Cross-case thematizing II: Developing first-, second-, and third-order themes |
| 3. | Final refining, checking, and reviewing |

Note that for these later phases of theme development, it was necessary to deviate from Braun and Clarke's [72] thematic analysis method. Theme development as per their guidelines involved subsuming lower-order themes into higher-order themes, resulting in the loss of valuable content. It was decided that losing the causal factors these themes represented was contrary to the research purpose. Researcher Gross remarked the same limitation [79, p. 56] and proposed the use of Attride-Stirling's [78] thematic network method in overcoming it, from which the researcher drew inspiration.

### Cross-case thematizing I: Intermediate analyses

The objective for the first level of cross-case thematizing was to sort themes developed individually in the within-case analyses and categorize them according to meaning and level of abstraction. For each trio of cases, the researcher began by reviewing their candidate themes and causal maps.

The researcher then sorted across each case, grouping together themes sharing similar meanings. This was done using a paper-based approach in which the researcher identified related themes across each case's causal map using colour-coded highlights. Selected preliminary themes and the codes they represented were then migrated to individual spreadsheets. Note that all candidate main themes, sub-themes, and sub-sub-themes from the within-case analyses were transferred.

The resulting sets of content-similar themes were then individually examined. First, themes with identical meanings were reduced by combining both and collecting codes under the single newly formed theme. Next, remaining themes were arranged. This involved categorizing the different levels of themes by classifying them according to their nuanced meanings and nesting more specific themes under more general ones. The researcher kept track of causal relationships from within-case analyses by formulating an intermediate causal map representative of the new set of themes. The end product for both intermediate cross-case analyses included (i) a set of condensed themes organized in a categorization system and (ii) a corresponding causal map of main themes.

Figure 3.8 captures the paper-based approach taken by the researcher for cross-case thematizing and for keeping track of the analysis throughout the research project. Note that the causal maps presented in this figure mirror the same order established in Figure 3.7. The reader is referred to Appendix B for additional material on this topic.


Figure 3.8: Causal maps from within-case and cross-case analyses presented per the order they were undertaken.

### Cross-case thematizing II: Developing first-, second-, and third-order themes

The objective for the second level of cross-case thematizing was to (i) merge and arrange the products of the intermediate analyses, (ii) abstract higher-order themes, and (iii) finalize the categorization system. This last phase of theme development yielded the final products of analysis: a set of thematic networks centred on themes at the highest-level of abstraction serving to organize and summarize the essence of the dataset.

The researcher began this phase by merging the results of both cross-case analyses to form a unified and comprehensive collection of sets of themes. This was done using the same spreadsheet and paper-based approach described in Cross-case thematizing I. Each set of themes—comprising main, sub-, and sub-sub-themes from across the various cases—was to be developed into a thematic network. The researcher worked successively through each set, first reviewing the comprising themes and reducing content-identical ones. Next, the remaining themes were arranged into first-, second-, and third-order themes. Second-order themes organize and capture the central meaning of first-order themes, which are the most basic and least abstract. Third-order themes are the core of the thematic network and capture the overarching meaning underlying the entire set.

Second- and third-order themes were either directly selected from the set of existing themes or were abstracted through an additional interpretive analysis step. The thematic networks structured from these first-, second-, and third-order themes effectively represent a finalized set of categories. Ultimately, this phase was for refining and formalizing the themes and categorization systems from previous phases such that they were representative of the entire dataset. Although straightforward, developing the structure of thematic networks was an effortful process requiring several iterations. Abstracting higher-order themes and organizing themes into content-related categories was not always obvious. As such, the finalized thematic networks and the categorization system (alternatively denoted the *conceptual framework*) they represent are not absolute. They were developed by the researcher to best reflect the raw data.

To conclude this phase, the researcher formulated the accompanying illustrations for the thematic networks as outlined in Subsubsection 3.6.2.4. Working titles and corresponding descriptions for every theme were compiled and a final causal map reflecting the changes made in this phase was developed. The outputs of this phase included (i) thematic networks (first-, second-, and third-order themes), (ii) corresponding descriptions of themes at every level, and (iii) a final causal map of third-order themes. These results are presented in the following Chapter 4. Ultimately, the original dataset was processed to yield a total of 17 thematic networks, representing 17 third-order themes, 48 second-order themes, and 86 first-order themes.

**Final refining, checking, and reviewing**

The final phase in this analytic method was for checking and reviewing the final products of analysis and making any necessary refinements. As suggested by Attride-Stirling [78, p. 393], checking and reviewing thematic networks involved examining first-, second-, and third-order themes and ensuring they were aligned with the base material from which they were developed. This required collating all codes and assessing whether or not they were properly represented by the first-, second-, and third- order themes they were supporting. The advice of Braun and Clarke [72, p. 91] was also followed. As such, the researcher checked that (i) data within themes “cohere[d] together meaningfully”, and (ii) distinctions between themes were “clear and identifiable”. This final phase resulted in several iterations of re-coding and reworking themes until stable and satisfactory thematic networks were obtained.

#### 3.7.2.3 Synthesis

This subsection detailed how the researcher analyzed qualitative data through use of an adapted thematic analysis method for developing first-, second-, and third-order themes from textual data. A summary of the transformation of the dataset into themes through this procedure is illustrated in Figure 3.9 as adapted from Mayring [77, p. 78]. The resulting themes capture some of the causal factors that positively and negatively influenced the development program for the *Model I* in achieving its objectives of schedule, cost, and quality.

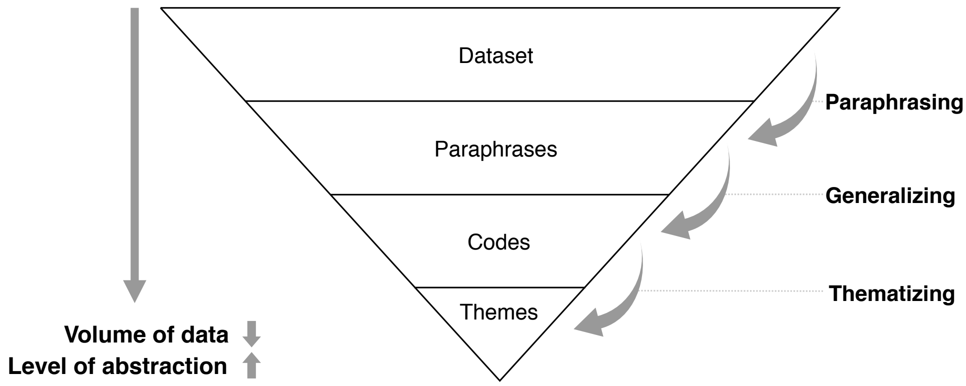


Figure 3.9: Transformation of the dataset through application of the analytic method, graphic adapted from Mayring [77, p. 78].

## 3.8 Validation of results

The final phase of the case study was a validation exercise intended to ensure the development of trustworthy and reliable results.

### 3.8.1 Review meetings: Validating and sharing results

After the first cross-case analysis was conducted, the researcher held a series of group meetings with respondents from the qualitative data collection phase (see Table 3.2) in order to present them with these intermediate analytic results. This review checkpoint is indicated in Figure 3.7. These meetings were a platform for sharing and discussing the emerging results of the qualitative analysis with the individuals directly responsible for generating the raw data. Most importantly, however, it was an opportunity for the researcher to validate the fidelity of the uncovered causal factors with attendees. Confirming that the emerging results were in fact representative of the accounts given during the interviews, by extension, served to validate that the analytic method was working effectively.

## 3.9 Chapter summary

This chapter detailed the *mixed-methods research design* of this study, which was a *pragmatically* oriented *case study* centred on the clean sheet development program for the *Model I*. Encompassed by this main case, major program phases/activities were considered as the *embedded level of analysis*. An initial *quantitative analysis* was conducted using archived program *documents* to inform the selection of embedded subunits of analysis. *Interviews* were implemented to generate qualitative data pertaining to the program and its fundamental successes and failures. Textual data was analyzed by means of an *adapted analytic method* for identifying recurring themes in the dataset. The resulting themes capture positive and negative causal factors affecting the development program. These results are presented in the following chapter.

# Chapter 4

# Results & Discussion: Themes from the case study of the *Model I*

*In the fourth chapter of this thesis*, the reader is presented with the results of the case study and a discussion of their significance.

## 4.1 Introduction

In support of an initiative to improve an aircraft manufacturer's generic product development (PD) process, a case study of an aircraft development program was undertaken to understand *why* programs overrun their baseline schedules in the context of the organization. The subject of the case study was the development program for the *Model I* undertaken by *AeroCo* to expand its existing product line with a completely new architecture aircraft. The program was found to have gone over schedule by roughly 26 months. The previous chapter detailed how the researcher generated and analyzed qualitative data as to develop insight into this overrun. This chapter presents the final products of the analysis.

## 4.2 Final products of analysis

The results of the application of the adapted analytic method include (i) first-, second-, and third-order themes organized into thematic networks and (ii) a final causal map.

### 4.2.1 Thematic networks: First-, second-, and third-order themes

In total, 17 thematic networks were developed, each centered on an overarching third-order theme and comprising a number of second- and first-order themes. Each thematic network captures a major pattern in the dataset and orders constituent lower-order themes by level of abstraction. Third-order themes are at the broadest level of abstraction whereas second- and third-order themes are increasingly more specific. The analytic method was configured to identify any significant *positive* and *negative* influences affecting the program in achieving its objectives of *schedule*, *cost*, and *quality*.[1] Thus, as extracted and refined from the raw data, themes represent

[1] Refer to Phase 1: *Establishing the configuration and parameters of the analysis* of Sub-subsection 3.7.2.1.

both positive and negative causal factors that played a role in the program's final outcome.

Thematic networks are presented in this subsection as a series of tables and figures. Tables indicate the varying levels of abstraction within each network and provide descriptions of each constituent theme. Each table is accompanied by a corresponding illustration as to display the same results in a format that is more easily accessible. The 17 overarching third-order themes along with their corresponding thematic network (table and figure) are listed here:

1. *Unexpected complications, undesirable outcomes*. See Table 4.1 and Figure 4.2.
2. *Making mistakes*. See Table 4.2 and Figure 4.3.
3. *Unforeseen, unplanned work, expenses, & delay*. See Table 4.3 and Figure 4.4.
4. *Less than fully optimized final design*. See Table 4.4 and Figure 4.5.
5. *Realistically unachievable initial objectives*. See Table 4.5 and Figure 4.6.
6. *Rushing, 'cutting corners'*. See Table 4.6 and Figure 4.7.
7. *Decreasing program team effectiveness & morale*. See Table 4.7 and Figure 4.8.
8. *Promoting program team effectiveness*. See Table 4.8 and Figure 4.9.
9. *Uncertainty, difficulty predicting*. See Table 4.9 and Figure 4.10.
10. *Successful strategizing, effective tactics*. See Table 4.10 and Figure 4.11.
11. *Suboptimal teamwork*. See Table 4.11 and Figure 4.12.
12. *Product development: process & management weaknesses*. See Table 4.12 and Figure 4.13.
13. *Limited past project learning*. See Table 4.13 and Figure 4.14.
14. *Inexperience, difficulty performing*. See Table 4.14 and Figure 4.15.
15. *Imperfect decision-making*. See Table 4.15 and Figure 4.16.
16. *Problematic program planning*. See Table 4.16 and Figure 4.17.
17. *Changing established plans, requirements*. See Table 4.17 and Figure 4.18.

Before individually examining each thematic network, the final causal map is presented in the following sub-subsection as it provides an overview of the results.

#### 4.2.1.1 Causal map

From the first within-case analysis, it became clear that emerging themes were interrelated and that the macro-level effects felt by the program were the culmination of multiple reinforcing interactions among micro-level causes. Recording these interrelationships among emerging themes was therefore important and causal maps were used to this end. The final causal map representative of the entire dataset is presented in Figure 4.1.[2] In this figure, themes are accompanied by reference numbers corresponding to the enumerated list above. The blue rounded rectangle in the bottom left-hand corner of the map represents the definitive effect or ultimate outcome to which themes directly and indirectly contribute. Most causal relationships are also noted in the descriptions of Tables 4.1 to 4.17.

The causal map reflects the significantly complex dynamic of an aircraft development program that makes it difficult to connect micro-level causes to macro-level outcomes. Williams notes that it is this nontrivial behaviour of higher complexity programs that impedes traditional lessons learned techniques from scaling to these applications [30]. A significant feature of this map is indicated by the blue arrows, colloquially referred to as the "Bermuda Triangle" by the researcher. The network of causal linkages connects Theme 1, 3, 4, and the ultimate outcome (UO). This

[2] An earlier iteration of this map is also pictured at the bottom of Figure 3.8.

specific interplay of causal factors is highlighted as it was found to be especially prevalent in the dataset.

This archetypal pattern is described below. Note that the boldface text on the left hand side is for situating the reader with respect to what is being described on the right hand side.

| | |
|---|---|
| **[Theme 1]** | A planned activity resulted in an undesirable outcome—or in other words—an unexpected complication arose from a planned action, such that: |
| **[Theme 1 → 3]** | (i) either additional work (expenses and delay), not initially accounted, for was required to address it, or |
| **[Theme 1 → 4]** | (ii) the complication was not significant enough to require an intervention, however undermined the final design of the product in some way. |
| **[Theme 3 → 4]** | In some instances, the additional work required to address the complication also contributed to undermining the final design of the product. This was seen in instances where it was required to rework existing designs in which the design space was already constrained and the only possible solutions were suboptimal (Theme 4.2.1). |
| **[Theme 3 → UO]**<br>**[Theme 4 → UO]** | Both unforeseen and unplanned work (Theme 3) and a less than fully optimized final design (Theme 4) contributed to the program's departure from its baseline objectives. |

In connection to this, a remarkable feature of the causal map is the number of factors contributing to Theme 1 which indirectly served to drive the aforementioned interplay.

Lastly, the arrow connecting Theme 13 to Theme 2 is also noteworthy as it features a seemingly conflicting causal relationship in which Theme 13 is simultaneously contributing to and mitigating Theme 2. This is emblematic of two contradictory themes developed from the dataset, Theme 13.1 and Theme 13.2, which are discussed later in Table 4.13.

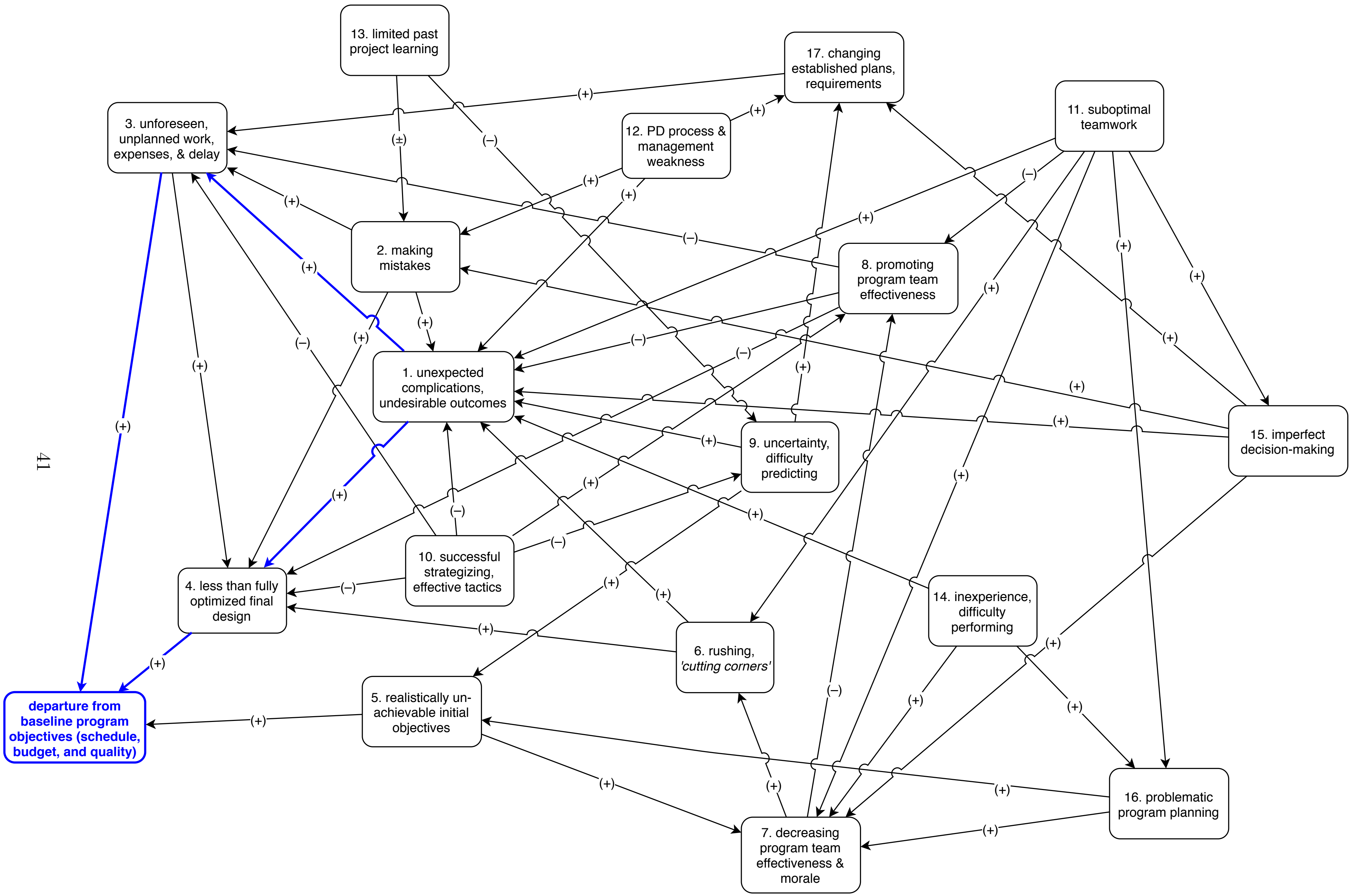


Figure 4.1: Final causal map illustrating cause and effect relationships among third-order themes.

#### 4.2.1.2 *Unexpected complications, undesirable outcomes*

This theme captures a pattern in the dataset pertaining to planned activities with expected outcomes, unexpectedly resulting in undesirable outcomes. Alternatively, it can be conveyed as unforeseen complications arising during planned activities with expected outcomes. As presented in Table 4.1 and illustrated in Figure 4.2, it encompasses 2 second-order themes and 7 first-order themes. Theme 1.1 organizes unanticipated technical issues with regards to the design of the product. The nested basic themes specify different aspects of development in which complications with the design were encountered. Theme 1.2 captures and organizes unforeseen complications with regards to the certification and validation process for the product. Theme 1.2.4 was of notable interest to the researcher as it remarks a dynamic aspect of certification regulations in which demonstrating compliance to new amendment levels may entail an unexpectedly significant effort.

Table 4.1: Thematic network summary of third-order Theme: *1. unexpected complications, undesirable outcomes*.

| Third-order theme | Second-order theme | First-order theme | Description |
|---|---|---|---|
| **1. unexpected complications, undesirable outcomes** | | | Unexpected complications occurring during development. Undesirable outcomes materializing. Causal factor in Theme 3 *unforeseen, unplanned work, expenses, and delay* and Theme 4 *less than fully optimized final design*. |
| | 1.1. unanticipated design issues | | Unanticipated technical issues with the design of the product. Causal factor in corrective rework and slowing development. |
| | | 1.1.1. finding surprises during testing | Discovering "unknown unknowns". Design issues inevitably uncovered in article testing and flight testing, late in the development. |
| | | 1.1.2. substandard subcontractor work | Design and development work subcontracted out, returning substandard quality, necessitating rework. |
| | | 1.1.3. design challenges | Encountering challenges designing and developing aspects of the aircraft. For example, integrating across disciplines. Causal factor in Theme 3.1 *corrective rework, fixing issues*. |
| | 1.2. unforeseen complications certifying and validating | | Unforeseen complications with certifying and validating the product. Causal factor in delay and rework. |
| | | 1.2.1. challenges agreeing, collaborating w/ NAA | OEM and national aviation authorities (NAA) encountering challenges in reaching consensus. |
| | | 1.2.2. unsatisfactory outcome to proven certification strategy | Strategy for certifying and validating the product successful in the past, not panning out as expected, giving less than satisfactory results. |
| | | 1.2.3. missing certification requirements | Failling to take into account certification requirements during the design phase, necessitating downstream corrective rework. |
| | | 1.2.4. unexpected rigour meeting latest amendment level | Unexpected rigour and stringency meeting the latest certification regulation amendment levels. |

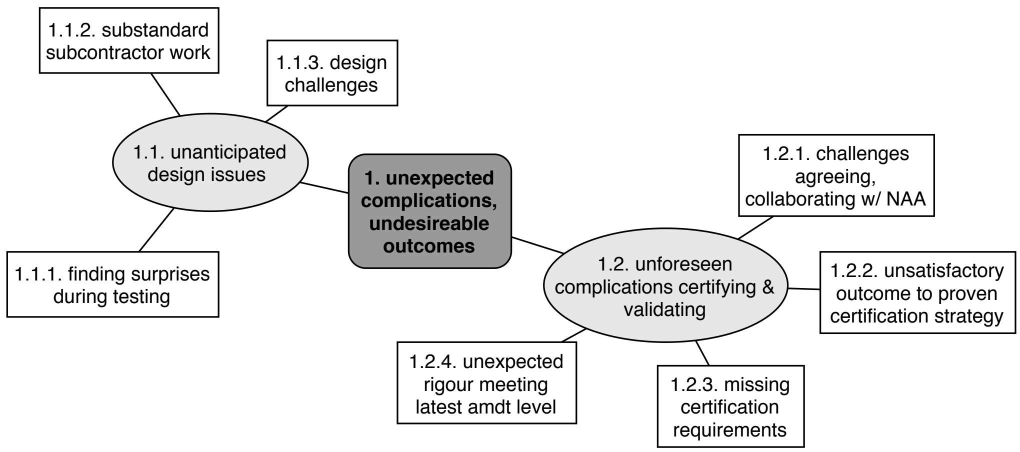


Figure 4.2: Thematic network illustration for third-order Theme: *1. unexpected complications, undesirable outcomes.*

#### 4.2.1.3 *Making mistakes*

Third-order Theme 2 captures a straightforward concept in the dataset. The organization of this theme is presented in Table 4.2 and Figure 4.3. Second-order Theme 2.1 embodies a pattern of situations underpinned with uncertainty that required a decision or judgment to be made which ultimately turned out to be mistaken. This theme was abstracted from two first-order themes as follows. Theme 2.1.1 specifies instances in which expectations or assumptions were made that did not hold true and Theme 2.1.2 specifies instances in which necessary estimates and approximations put forth were simply inaccurate.

Second-order Theme 2.2 organizes high-risk actions and decisions that were taken on the program which resulted in negative consequences. The encompassed first-order themes specify various instances of these suboptimal decisions taken throughout the program. First-order Theme 2.2.1 was especially prevalent in the dataset. Second-order Themes 2.1 and 2.2 are differentiated in that the former is to a degree unavoidable given the nature of uncertainty whereas the latter captures decisions of a higher magnitude that recur on programs and can thus be better mitigated in the future. Second-order Theme 2.3: *repeating mistakes*, is a standalone theme that captures the concept of making mistakes that were already previously experienced on an earlier program. In the dataset, these mistakes were described as “preventable” and “avoidable”.

Table 4.2: Thematic network summary of third-order Theme: *2. making mistakes*.

| Third-order theme | Second-order theme | First-order theme | Description |
|---|---|---|---|
| **2. making mistakes** | | | Doing something incorrectly (misguided judgments and actions), resulting in Theme 1: *unexpected complications, undesirable outcomes*, Theme 3: *unforeseen, unplanned work, expenses, and delay*, and Theme 4: *less than fully optimized final design*. |
| | 2.1. necessary but misguided decisions | | Necessary decisions made in the face of incomplete information that were ultimately mistaken. |
| | | 2.1.1. false assumptions & expectations | Assumptions and expectations used for drawing conclusions believed to be true although actually incorrect. |
| | | 2.1.2. misestimating, underestimating | Improperly approximating real-life parameters, values, and magnitudes. For example, costs, efforts, lead times... |
| | 2.2. suboptimal decisions yielding negative outcomes | | Actions and decisions taken that exposed the program to a high-risk of complication and ultimately resulted in negative outcomes. Effect of Theme 15: *imperfect decision-making*. |
| | | 2.2.1. incorporating low RL concepts, developing technology concurrent to product | Incorporating new, low readiness level (RL) technologies in the aircraft design, requiring technology development concurrent to product development. Draws attention away from product development and is a causal factor in Theme 1. |
| | | 2.2.2. incorporating unconventional design concepts | Incorporating concepts in the aircraft design with which the organization is inexperienced. Unconventional design concepts with respect to organization's product line. Causal factor in Theme 1. |
| | | 2.2.3. foregoing provisions for risk mitigation | Making-high risk decisions without adequate risk mitigation measures for scenarios in which risks materialize. |
| | | 2.2.4. committing to production with low RLs, unproven designs | Committing to production with low readiness level (RL) designs, prior to finishing comprehensive testing, is a causal factor in high-consequence corrective rework (Theme 3) and in Theme 4. |
| | | 2.2.5. subcontracting inexperienced suppliers | Subcontracting design and development work within the organization's expertise to inexperienced suppliers was longer, more expensive, and of lower quality. Causal factor in Theme 3 and Theme 4. |
| | 2.3. repeating mistakes | | Making the same mistakes from one program to the next. Repeating avoidable mistakes. |

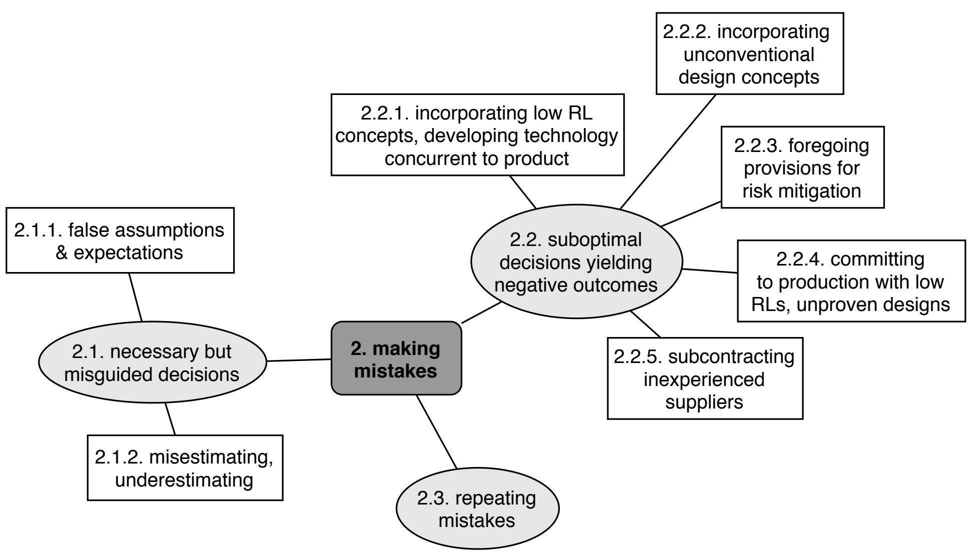


Figure 4.3: Thematic network illustration for third-order Theme: *2. making mistakes*.

#### 4.2.1.4 *Unforeseen, unplanned work, expenses, & delay*

*Unforeseen, unplanned work, expenses, & delay* was an overarching theme developed from the dataset, as presented in Table 4.3 and Figure 4.4. The 3 elements of this theme are related such that additional *work* efforts generally entail additional *expense* and *delay*. This theme was notably prevalent in the dataset and conceptualized as the effect of *making mistakes* (Theme 2) and *unexpected complications, undesirable outcomes* (Theme 1). It represents a significant causal factor in the program's departure from its baseline objectives. This theme is organized into two separate categories as follows. Second-order Theme 3.1—*rework*—was an especially ubiquitous pattern and the most frequently noted causal factor affecting the program in the dataset. It encompasses two first-order themes which specify noteworthy variations of the concept. Second-order Theme 3.2 captures the straightforward concept of delay on the program due to waiting and organizes different sources thereof.

Table 4.3: Thematic network summary of third-order Theme: *3. unforeseen, unplanned work, expenses, & delay.*

| Third-order theme | Second-order theme | First-order theme | Description |
|---|---|---|---|
| **3. unforeseen, unplanned work, expenses, & delay** | | | Additional work activities, lead times, and associated expenses not initially planned nor budgeted for. Causal factor in the program's departure from its baseline objectives of schedule and budget. |
| | 3.1. corrective rework, fixing issues | | Revising activities previously completed upstream to fix issues. Generally considered wasteful as it is a corrective response to something incorrectly done the first time. |
| | | 3.1.1. reworking under production CM | Reworking designs under production configuration management (CM) incurs heavy review process: particularly lengthy and expensive. |
| | | 3.1.2. incidental rework: upstream changes, downstream repercussions | Changes to an aspect of the design made upstream, having an impact on the design of a separate aspect downstream, incidentally causing rework. |
| | 3.2. downtime, waiting | | Putting progress on hold, waiting for a lead time to expire. |
| | | 3.2.1. waiting for suppliers | Delaying work, waiting for a supplier to deliver. |
| | | 3.2.2. waiting for dependent tasks | Delaying work, waiting for completion of upstream dependent task. |

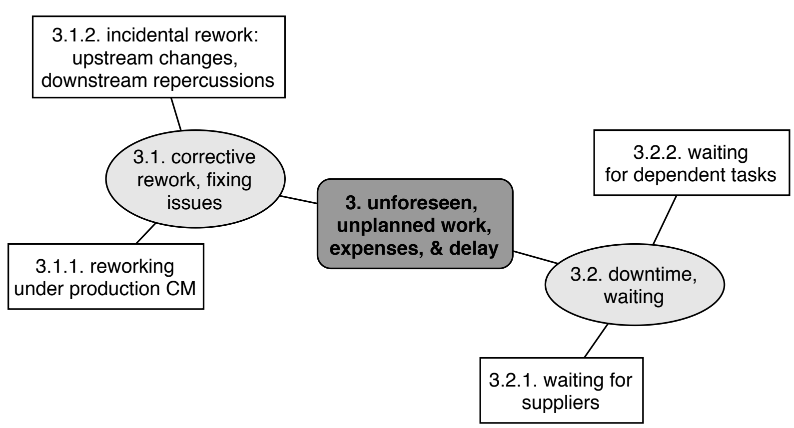


Figure 4.4: Thematic network illustration for third-order Theme: *3. unforeseen, unplanned work, expenses, & delay.*

#### 4.2.1.5 *Less than fully optimized final design*

This theme was abstracted to capture a pattern in the dataset that the final design of the product, although highly capable, was not optimized to the highest possible degree. Total optimization is realistically unachievable, however this theme embodies an idea among respondents that the best possible design was not attained. This network, presented in Table 4.4 and Figure 4.5, is organized along two optimization parameters: profitability (Theme 4.1) and quality (Theme 4.2). The first-order themes encompassed under Theme 4.1 are instances in which the design was not fully optimized at the perceived detriment of the product's profitability. Whereas, the first-order themes encompassed under Theme 4.2 are instances in which the design was not fully optimized at the perceived detriment of the product's quality. Note that Theme 4.2.1: *reworking designs, compromised solutions* is an incidental negative consequence driven by Theme 3.1: *corrective rework, fixing issues.*

Table 4.4: Thematic network summary of third-order Theme: *4. less than fully optimized final design.*

| Third-order theme | Second-order theme | First-order theme | Description |
|---|---|---|---|
| **4. less than fully optimized final design** | | | Design of the final product acceptable and airworthy although less than fully optimized. |
| | 4.1. less than optimal designs, undermining profitability | | Developing acceptable and airworthy designs not fully optimized for cost and turn-around time. |
| | | 4.1.1. choosing inappropriate design tolerances | Choosing tolerances for components that do not match their application either overly stringent or too loose and needlessly driving up costs and/or part rejection (indirectly incurring costs). |
| | | 4.1.2. neglecting design manufacturability | Neglecting to optimize designs for ease of manufacturability, needlessly driving up costs and turn-around time. |
| | | 4.1.3. over-designing, unnecessarily complex | Developing unnecessarily complex design solutions, needlessly driving up costs and turn-around time. |
| | 4.2. acceptable design shortcomings, undermining quality | | Developing acceptable and airworthy designs not at the highest achievable level of quality for cost. |
| | | 4.2.1. reworking designs, compromised solutions | Compromised design solutions as a result of reworking designs with surrounding constraints already in place/frozen. Only possible design solutions are suboptimal: more expensive and of lower-quality. Outcome of Theme 3.1: *corrective rework, fixing issues*. |
| | | 4.2.2. low effort, minor defects | Minor, low quality defects as a result of low effort and inattention. For example, tertiary structure imperfections. Outcome of Theme 6: *rushing, 'cutting corners'*. |

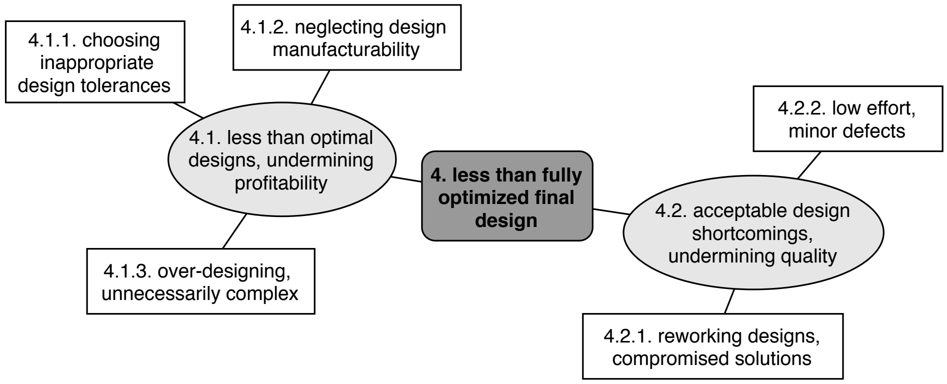


Figure 4.5: Thematic network illustration for third-order Theme: *4. less than fully optimized final design.*

#### 4.2.1.6 *Realistically unachievable initial objectives*

Third-order Theme 5 constitutes another prevalent pattern in the dataset concerning the notion that from the very beginning, the baseline objectives of schedule and budget set for the program could not be met based on realistic performance. Table 4.5 and Figure 4.6 present the categorization scheme for this thematic network. Second-order Theme 5.1 captures *what* was unrealistic about the schedule objective whereas, Theme 5.2 captures *what* was unrealistic about the budget objective. As nested in second-order Theme 5.1, first-order Theme 5.1.1 provides insight into the unattainability of the schedule as it captures the recounted scheduling practice of minimizing contingency reserves. This is noteworthy given that unexpected complications were actually found to have arisen during the development as captured by Theme 1.

Ultimately, as a causal factor in the program's departure from its baseline objectives, Theme 5 conveys that the magnitude of departure was in part attributable to the inaccuracy of the projected baseline objectives.

Table 4.5: Thematic network summary of third-order Theme: *5. realistically unachievable initial objectives.*

| Third-order theme | Second-order theme | First-order theme | Description |
|---|---|---|---|
| **5. realistically unachievable initial objectives** | | | Initial baseline objectives of budget and schedule unrepresentative of real-life performance. Realistically unachievable challenge-based targets from program launch. |
| | 5.1. overambitious, overaggressive schedule | | Schedule too short for the true scope of work. |
| | | 5.1.1. success oriented, no margin for error | Minimizing the allocation of schedule reserve or *buffer* in the schedule, a decision based on the assumption there will be no unexpected complications (Theme 1). |
| | 5.2. underfunded program | | Not enough budget for the true scope of work. |

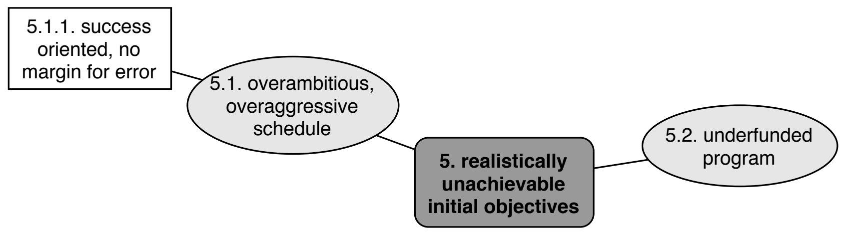


Figure 4.6: Thematic network illustration for third-order Theme: *5. realistically unachievable initial objectives.*

#### 4.2.1.7 *Rushing, 'cutting corners'*

Theme 6 encompasses a pattern of rushing through and skipping steps in the development process. The organization of this main theme is presented in Table 4.6 and Figure 4.7. Its two comprising second-order themes are distinguished according to *skipping* (Theme 6.1) and *rushing* (Theme 6.2) aspects of development. This main theme and its encompassing aspects were indirect drivers in the program's departure from its baseline objectives. Overall this theme captures a salient facet of the dataset that illustrates a scenario where, in the face of mounting pressure, the program made concessions in order to work quickly and avoid expenses in the short-term, however, in doing so, may have actually generated more work and expenses in the long-term. It is also interesting to note the influence of basic Theme 11.2.1: *decision maker and technical expert disconnect, lack of shared understanding* in contributing to this scenario.

Table 4.6: Thematic network summary of third-order Theme: *6. rushing, 'cutting corners'*.

| Third-order theme | Second-order theme | First-order theme | Description |
|---|---|---|---|
| **6. rushing, 'cutting corners'** | | | Rushing through development and omitting steps in the product development process. Driven by the high demands put on the program team (Theme 7.1). |
| | 6.1. skipping development activities | | Skipping development activities to save time and expense short term, triggering issues downstream. Led to a false sense of progress and was a causal factor in Theme 12.5.2: *progressing low RL designs late into development*. |
| | | 6.1.1. bypassing design scale-up | Jumping from design on paper directly to full-scale testing. Forgoing design scale-up, curtailing activities dedicated to maturing, iterating, and learning about the design. Upfront expense and time investment, mitigates issues downstream. Causal factor in Theme 1.1: *unanticipated design issues*. Outcome of the disconnect between technical experts and decision makers (Theme 11.2.1). |
| | 6.2. rushing development | | Working quickly through development, at the expense of thoroughness. Causal factor in Theme 4.2.2: *low effort, minor defects*. |

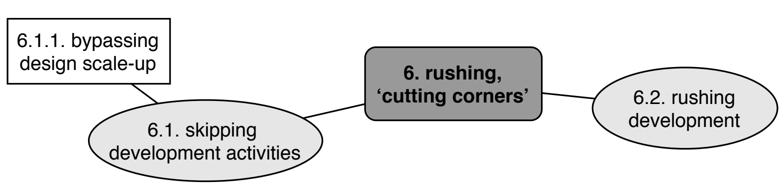


Figure 4.7: Thematic network illustration for third-order Theme: *6. rushing, 'cutting corners'*.

#### 4.2.1.8 *Decreasing program team effectiveness & morale*

Theme 7 integrates a pattern in the dataset pertaining to prolonged development and a discernable weakening of program team effectiveness and morale. This theme comprises 2 second-order themes and 4 first-order themes as presented in Table 4.7 and Figure 4.8. Second-order Theme 7.1 was abstracted to capture the notion of chronic stress exerted on the program team from high and seemingly overwhelming demands hindering the ability to execute at the individual level. The relationship shared between nested Theme 7.1.1 and Theme 5 *realistically unachievable initial objectives* was such that the overaggressive targets contributed to the perception of pressure. Basic Theme 7.1.2 captures an insightful element of the dataset pertaining to a workflow bottleneck at the level of middle management incidentally driving Theme 2 *making mistakes*. Second-order Theme 7.2 is centered of the notion of negative team chemistry and low morale underlying aspects of the program team. It was abstracted from basic Themes 7.2.1 and 7.2.2 which organize instances thereof.

Table 4.7: Thematic network summary of third-order Theme: *7. decreasing program team effectiveness & morale.*

| Third-order theme | Second-order theme | First-order theme | Description |
|---|---|---|---|
| **7. decreasing program team effectiveness & morale** | | | Development wearing on the program team, effectiveness and morale showing signs of weakening. |
| | 7.1. high demands, difficulty coping | | High demands on individuals to produce, inducing stress, hindering ability to perform effectively. Causal factor in Theme 6: *rushing, 'cutting corners'*. |
| | | 7.1.1. schedule and workload pressure | Excessive workload and limited available time, putting pressure on individuals to produce. Outcome of Theme 5: *realistically unachievable initial objectives*. |
| | | 7.1.2. leadership overload, bottleneck | Overwhelming responsibilities and excessive demand on middle management, compromising ability to effectively lead and manage. Causal factor in Theme 2: *making mistakes*. |
| | 7.2. weakening team chemistry, low morale | | Decreasing program team morale and weakening of team chemistry. |
| | | 7.2.1. assigning blame | Blaming individuals/groups for unfavourable complications and mistakes. |
| | | 7.2.2. growing practitioner frustration | Growing frustration among front-line practitioners. Outcome of Theme 15.1.1: *executive decision-making*. |

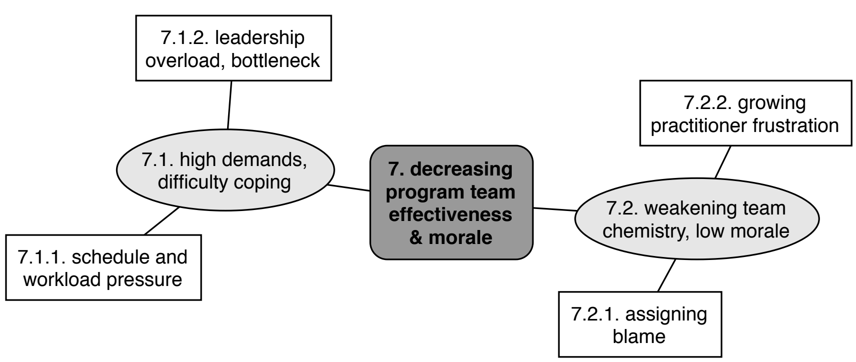


Figure 4.8: Thematic network illustration for third-order Theme: *7. decreasing program team effectiveness & morale.*

#### 4.2.1.9 *Promoting program team effectiveness*

Theme 8 incorporates measures that served to promote the effectiveness of the program team and represents a positive causal factor underlying the development. This theme is categorized as presented in Table 4.8 and Figure 4.9. Second-order Theme 8.1 captures the straightforward concept that an effective team is comprised of effective team members. The nested basic themes specify aspects of *recruiting* (Theme 8.1.1) and *developing* (Theme 8.1.2) these individuals.

Second-order Theme 8.2 captures the concept of improving the efficiency of the program team workflow through tangible measures, as specified by the basic themes encompassed within. Special attention is brought to Theme 8.2.2 which identifies working in parallel as an effective approach to "compressing" the schedule although at the detriment of increased expenses. Theme 8.2.3 is also noteworthy as it highlights the importance of maintaining a cohesive program team by emphasizing alignment and coordination such that all independent elements progress together uniformly. Lastly, second-order Theme 8.3 was developed from the dataset to capture the concept of program team ramp-up and the obstacle it typically represents during development. Developing a plan to manage ramp-up was found to have streamlined this challenge and first-order Theme 8.3.1 specifies a tangible measure of that plan.

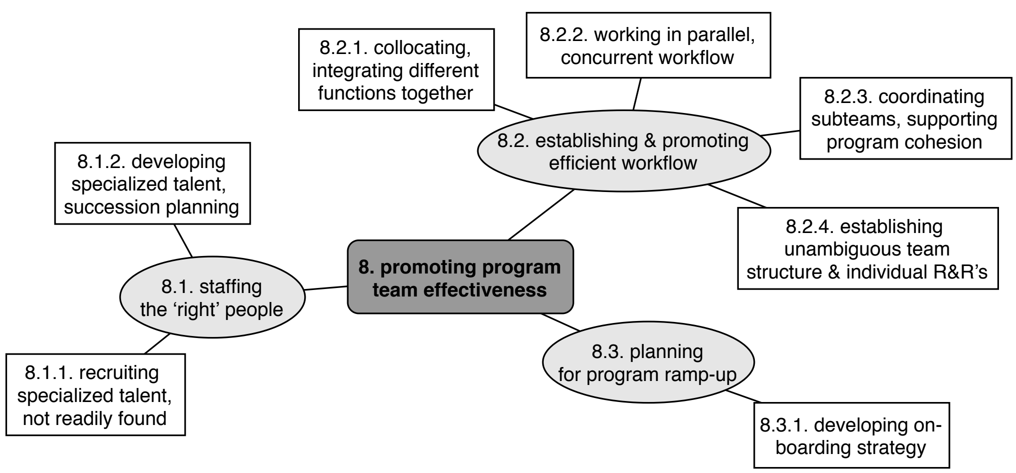


Figure 4.9: Thematic network illustration for third-order Theme: *8. promoting program team effectiveness.*

Table 4.8: Thematic network summary of third-order Theme: *8. promoting program team effectiveness.*

| Third-order theme | Second-order theme | First-order theme | Description |
|---|---|---|---|
| **8. promoting program team effectiveness** | | | Putting measures in place to promote an effective program team. |
| | 8.1. staffing the 'right' people | | Staffing the program team with strong, reliable contributors capable of effectively supporting the program. |
| | | 8.1.1. recruiting specialized talent, not readily found | Recruiting specialized talent profile not readily found on the open market, including specialized skills, unique personal attributes, and requisite level of experience. |
| | | 8.1.2. developing specialized talent, succession planning | Developing a specialized talent profile from within the organization talent pool, including specialized skills, unique personal attributes, and requisite level of experience. A necessary part of succession planning. |
| | 8.2. establishing & promoting efficient workflow | | Developing and maintaining an organized and collaborative workflow within the program team. Efficient workflow arrangements, serving to improve overall performance. |
| | | 8.2.1. collocating, integrating different functions together | Seating various functions together and integrating traditionally supporting functions into the program team to promote collaboration. Causal factor in minimizing schedule lag (Theme 3.2), optimizing the design (Theme 4), and mitigating difficulties designing (Theme 1.1.3). |
| | | 8.2.2. working in parallel, concurrent workflow | Functions of the program team working in parallel with unreleased engineering. Minimizes schedule lag (Theme 3.2) although contributes to unnecessary expense as commitments are made with in-work designs subject to change. |
| | | 8.2.3. coordinating subteams, supporting program cohesion | Aligning and coordinating individual elements (subteams), supports overall cohesive program progress. Promoted by a shared understanding of requirements (Theme 10.7) and undermined by ineffective communication (Theme 11.1). |
| | | 8.2.4. establishing unambiguous team structure & individual R&R's | Establishing an unambiguous organizational structure—or chain of command—at all levels of the program team, wherein clear roles and responsibilities (R&R's) are defined for each team member. Serves to enhance smooth and efficient operation. |
| | 8.3. planning for program ramp-up | | Planning and implementing measures for streamlining program team ramp-up. Mitigating factor in Theme 3.2. |
| | | 8.3.1. developing on-boarding strategy | Strategizing integration of individuals into teams, enhances on-boarding efficiency. |

#### 4.2.1.10 *Uncertainty, difficulty predicting*

Theme 9 captures a pattern pertaining to the existence of an ineliminable degree of uncertainty underlying predictions made throughout the program. As presented in Table 4.9 and Figure 4.10, this theme is primarily organized into two categories: uncertainty underlying design (Theme 9.1) and uncertainty underlying planning (Theme 9.2).

Second-order Theme 9.1 captures a pattern of some elements of the aircraft's design exhibiting unpredictable performances/behaviours given limitations in the modelling and simulation of some especially complex use cases. These instances in which the aircraft or specific systems exhibited unintended behaviours were evidently a causal factor in Theme 1.1.1 *finding surprises during testing*. This second-order theme encompasses Theme 9.1.1 which captures the existence of markedly difficult to model systems that have been problematic across multiple development programs. It was noted in the dataset that these systems could benefit from more robust modelling capabilities, as captured in Theme 10.6.1, which would serve to mitigate this aspect of uncertainty.

Second-order Theme 9.2 captures the notion that the plans developed for the program, in some instances, could be reduced to a "best guess" of how the future will unfold. As nested in this second-order theme, Theme 9.2.1 specifies a source of ineliminable uncertainty in a plan. Lastly, Theme 9.3 represents a standalone second-order theme identified in the dataset simply noting *luck* as a factor influencing the outcome of some situations. This theme did not perfectly fit any of the two aforementioned categories although transcends the overarching theme of uncertainty.

Table 4.9: Thematic network summary of third-order Theme: *9. uncertainty, difficulty predicting.*

| Third-order theme | Second-order theme | First-order theme | Description |
|---|---|---|---|
| **9. uncertainty, difficulty predicting** | | | Existence of some level of uncertainty given the inability to predict future outcomes. Forecasts are imperfect, ends are to a degree unpredictable. |
| | 9.1. imperfect modelling, design performance unpredictability | | Limitations in the modelling capabilities for some aspects of the aircraft's design, resulting in real life performances/behaviours that are difficult to accurately predict. Causal factor in Theme 1.1.1: *finding surprises during testing*. |
| | | 9.1.1. historically recurring problematic systems | Specific aircraft systems recurringly problematic across different platforms in the organization's history, indicative of difficulty modelling. |
| | 9.2. limited visibility planning | | Limits to what is known beforehand when planning, uncertainty underlying what needs to be done and corresponding effort required to do so. Causal factor in Theme 5: *realistically unachievable initial objectives*. |
| | | 9.2.1. unforeseeable, uncontrollable factors, 'acts of god' | Unpredictable incidents beyond control affecting the program. For example, global economic shifts due to viral outbreak. Causal factor in Theme 17: *changing established plans, requirements*. |
| | 9.3. factor of luck | | Chance influencing some outcomes. |

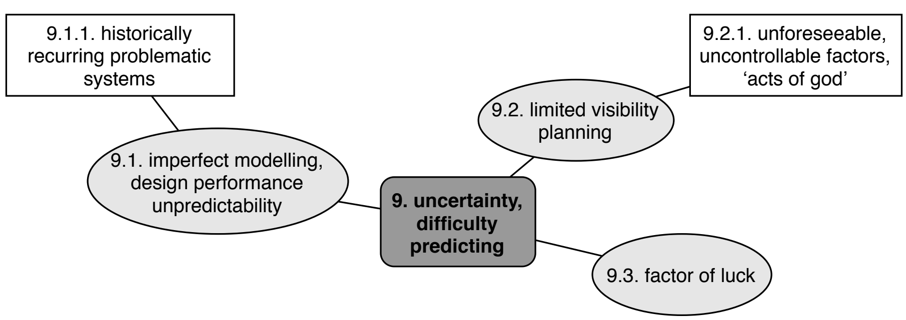


Figure 4.10: Thematic network illustration for third-order Theme: *9. uncertainty, difficulty predicting.*

#### 4.2.1.11 *Successful strategizing, effective tactics*

Theme 10 is a general theme that captures the development and implementation of effective strategies and tactics that served to improve both the execution and final output of the program. This theme represents a positive causal factor underlying the development. The terms "strategy" and "tactic" were selected to convey the characterizing facet of this theme such that these successful approaches were both carefully considered and clever. These terms are mostly used interchangeably, however in this view, tactics are less extensive than strategies with respect to scope. As presented in Table 4.10 and Figure 4.11, this theme is organized into second-order themes by the areas of aircraft development which benefited from the implementation of effective strategies/tactics. First-order themes capture specific considerations or more tangible and actionable items.

The importance of Second-order Theme 10.2 and its nested first-order themes was emphasized in the dataset. It was reported as an aspect of development vital to carefully consider and strategize and that, if mishandled, could significantly derail an entire program. Another particularly interesting theme in this network was second-order Theme 10.6. The value of tightly managing design readiness levels throughout development was of new insight to the researcher. Lastly, although Theme 10.8 seems obvious, the noteworthy feature of this theme was the uniform dissemination of requirements to every element in the program team and its value in keeping the program team aligned (Theme 8.3.1).

Third-order Themes 8 and 10 both represent the only exclusive positive causal factors identified on the program. The difference between them is such that Theme 8 pertains to the people and arrangement of the program team whereas Theme 10 pertains to aspects of the design and development process. Note that Theme 10 acts as a "catch-all" in this regard.

Table 4.10: Thematic network summary of third-order Theme: *10. successful strategizing, effective tactics.*

| Third-order theme | Second-order theme | First-order theme | Description |
|---|---|---|---|
| **10. successful strategizing, effective tactics** | | | Developing and implementing successful strategies and effective tactics, improving program execution. Causal factor in mitigating the ultimate outcome. |
| | 10.1. strategizing tooling approach | | Evaluating different approaches to assembly line tooling and corresponding trade-offs. Mitigating factor in Theme 4: *less than fully optimized final design*. |
| | | 10.1.1. considering DBB decisions, partnerships | Considering trade-offs of different design, build, and buy (DBB) options for tooling. |
| | | 10.1.2. considering tooling design solution trade-offs | Evaluating trade-offs of different tooling design solutions: economic philosophies (cost vs. lifespan), shop floor preferences, and the impact of product design choices on the cost and complexity of tooling. |
| | 10.2. strategizing certification & validation process | | Developing a thought-out and measured approach to certifying and validating with the agencies, reducing risk of Theme 1.2: *unforeseen complications certifying and validating*. |
| | | 10.2.1. planning regular, careful communication protocol | Developing a planned protocol for regular and careful communication between organization and agencies. |
| | | 10.2.2. managing delicate working relationships | Delicately approaching professional working relationship between the organization and agencies, fostering good rapport. |
| | | 10.2.3. planning the path to compliance | Many different paths exist to demonstrating compliance, emphasis on developing a tailored approach suitable for the specific program and current climate. |
| | 10.3. streamlining flight testing | | Streamlining the execution of flight testing with effective tactics. Mitigating factor in Theme 3.2: *downtime, waiting*. |
| | | 10.3.1. strategic flight testing methodology | Specific methodology guiding experimental flight testing optimized rectifications and response times, ultimately expediting the activity. |
| | 10.4. streamlining design work | | Streamlining design work with effective tactics. |
| | | 10.4.1. developing technical design SOPs | Developing and documenting high-level standard operating procedures (SOPs) for systematically and uniformly designing (guidelines & manuals). |

| | | |
|---|---|---|
| 10.5. considering future platform upgrades | | Taking into account foreseeable future platform upgrades in the design of the basic aircraft. Mitigating factor in Theme 4. |
| | 10.5.1. allocating provisions for optional features | Making necessary allocations to accommodate optional feature packages in the design of the basic aircraft. |
| 10.6. emphasizing upfront risk reduction & RL management | | Emphasis on risk reduction and maturing design readiness levels (RLs) early and assessing them throughout the program. Mitigating factor in Theme 1.1: *unanticipated design issues* and in Theme 4. |
| | 10.6.1. bolstering modelling capabilities | Investing in higher fidelity and more robust modelling tools to better predict system behaviour, mitigating factor in Theme 9.1: *imperfect modelling, design performance unpredictability*. |
| | 10.6.2. upstream, risk-reduction testing | Early testing of high-risk systems to reduce design uncertainty (Theme 9). |
| | 10.6.3. progressing based on readiness levels | Making decisions to advance the program based on attaining maturity and readiness levels. |
| | 10.6.4. rapid prototyping & iterating early in development | Development strategy with focus on upfront prototyping and iteration, effective for (i) learning about, (ii) maturing, and (iii) validating the design early. |
| 10.7. establishing and disseminating robust requirements | | Establishing unambiguous and universally understood requirements, promotes program team alignment and cohesive progress (Theme 8.3.1). |
| | 10.7.1. forecasting market requirements | Forecasting performance requirements to future market capability as the development timeline affords [redacted]. |
| 10.8. anticipating notoriously long lead times | | Anticipating and planning for items and services with notoriously long procurement lead times. For example, cast and forged parts... |

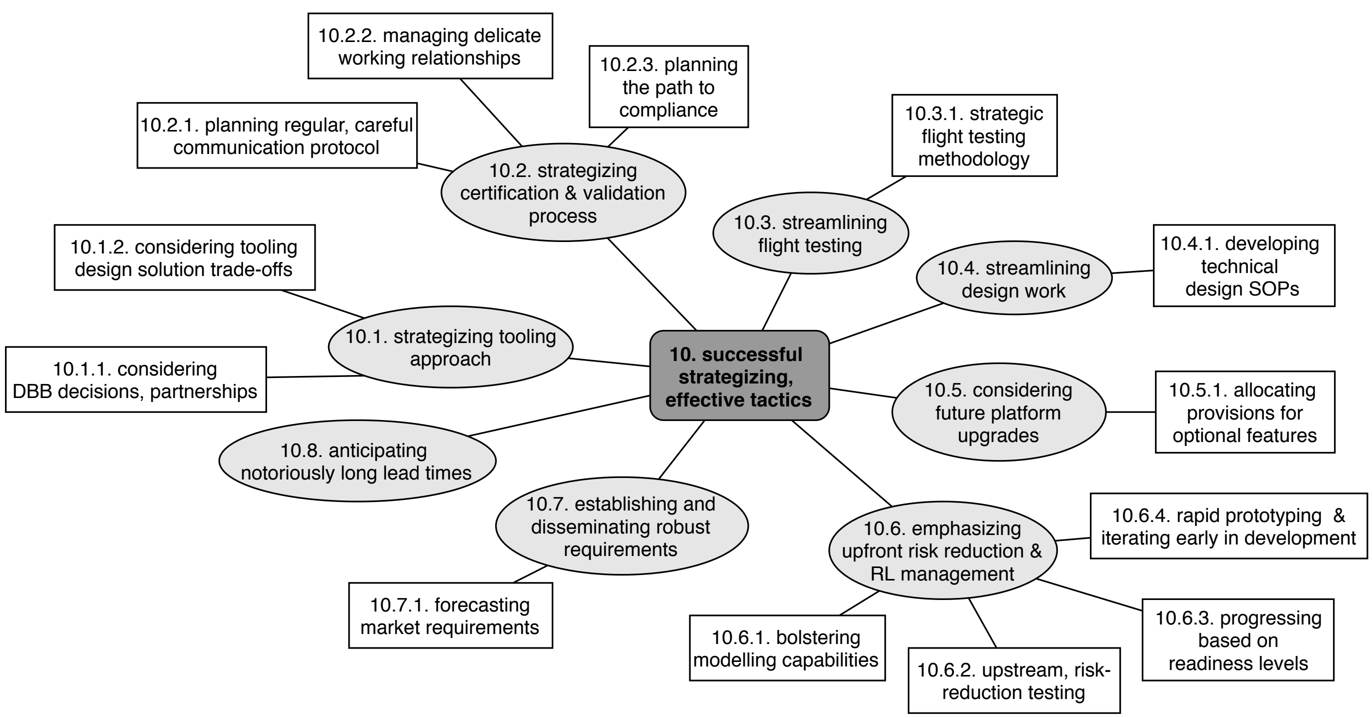


Figure 4.11: Thematic network illustration for third-order Theme: *10. successful strategizing, effective tactics.*

#### 4.2.1.12 *Suboptimal teamwork*

Theme 11 was developed from the dataset to capture and organize instances of poor teamwork among elements contributing to the program both internal and external to the organization. It represents a negative causal factor present on the development. As presented in Table 4.11 and Figure 4.12, this thematic network is categorized according to different aspects undermining teamwork. Second-order Theme 11.2 was carefully worded as to unify the nested first-order themes under the notion that these working relationships were functional but not particularly cooperative. First-order Theme 11.2.1 specifies a noteworthy instance of this concept as it represents an inconspicuous although impactful negative causal factor. Also, note that second-order Theme 11.3 is the inverse of Theme 8.2: *establishing & promoting efficient workflow*.

Table 4.11: Thematic network summary of third-order Theme: *11. suboptimal teamwork*.

| Third-order theme | Second-order theme | First-order theme | Description |
|---|---|---|---|
| **11. suboptimal teamwork** | | | Suboptimal teamwork among contributors direct and indirect to the program hindering performance. |
| | 11.1. ineffective communication | | Ineffective communication, inadequate information flow through the program team. |
| | | 11.1.1. one-way communication, lack of feedback | One-way communication from the top-down, lack of communication from the bottom-up. Ultimately front-line practitioner feedback ignored. Causal factor in Theme 7.2.2: *growing practitioner frustration* and undermines Theme 8.2.3: *coordinating subteams, supporting program cohesion*. |
| | 11.2. inharmonious working relationships | | Inharmonious working relationships internal and external to the organization. Causal factor in Theme 1: *unexpected complications, undesirable outcomes* and Theme 15: *imperfect decision-making*. |
| | | 11.2.1. decision maker and technical expert disconnect, lack of shared understanding | Technical experts responsible for executing work and upper level management responsible for making decisions not on the same page. Lack of shared understanding of the consequences of program decision between both levels. Causal factor in Theme 6.1.1 and Theme 16.3. |
| | | 11.2.2. personality conflicts, low rapport | Colleagues not gelling, unable to effectively collaborate. |
| | | 11.2.3. disjointed generational values | Low-level disunity from clashing generational values among contributors. |
| | 11.3. inefficient workflow & organization | | Inefficient arrangements for working together and getting work done. |
| | | 11.3.1. throwing work over the fence, 'siloed' working arrangement | Offloading work to an independent team with little to no collaboration, getting back substandard results. Causal factor in Theme 1. |
| | | 11.3.2. ambiguous organizational structure at practicioner level | Organizational structure and individual roles and responsibility undefined at the practicioner level. Difficult working arrangement to manage. Causal factor in Theme 7.1.2: *leadership overload, bottleneck*. |

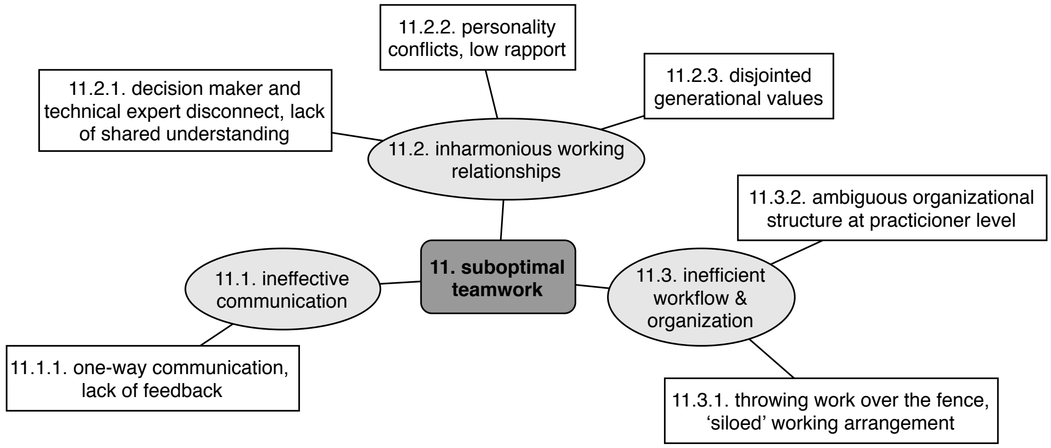


Figure 4.12: Thematic network illustration for third-order Theme: *11. suboptimal teamwork*.

#### 4.2.1.13 *Product development: process & management weaknesses*

Theme 12 captures shortcomings in the product development (PD) process and other program management mechanisms as a negative causal factor affecting the program. The organization of this theme is presented in Table 4.12 and Figure 4.13. Second-order Themes 12.1 and 12.2 respectively pertain to the *application* and *design* of the PD process model. Interestingly, these second- and first-order themes are in line with the practical weaknesses of the stage-gate process model as reported in the research literature reviewed in Section 2.4. The first-order themes encompassed by Theme 12.3 are differentiated in that Theme 12.3.1 pertains to review by peers on the program team whereas Theme 12.3.2 pertains to review by individuals independent to the program and possibly the organization. Also, note that second-order Theme 12.5 is the inverse of Theme 10.7: *emphasizing upfront risk reduction & RL management*. The nested first-order Themes 12.5.1 and 12.5.2 are related in that the latter is a symptom of the former.

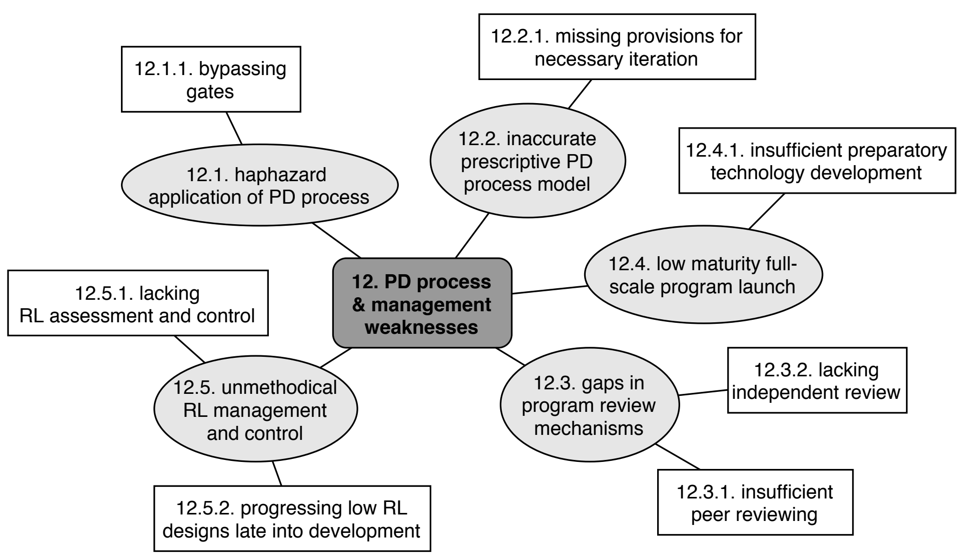


Figure 4.13: Thematic network illustration for third-order Theme: *12. product development: process & management weaknesses*.

Table 4.12: Thematic network summary of third-order Theme: *12. product development: process & management weaknesses.*

| Third-order theme | Second-order theme | First-order theme | Description |
|---|---|---|---|
| **12. PD process & management weaknesses** | | | Weaknesses in the company-level prescriptive product development (PD) process (model design and application thereof) and other mechanisms for managing the program. |
| | 12.1. haphazard application of PD process | | Haphazard adherence to and application of prescriptive company-level PD process, sidestepping process requirements and not comprehensively following. |
| | | 12.1.1. bypassing gates | Bypassing prescriptive PD process mechanisms for controlling the program, gates passed without meeting all requirements. |
| | 12.2. inaccurate prescriptive PD process model | | Prescriptive PD process model not accurately reflecting the actual underlying design and development process. |
| | | 12.2.1. missing provisions for necessary iteration | PD process model design missing provisions for necessary iteration loops needed for designing and developing. For example, integrating aircraft systems. Causal factor in Theme 1.1.3: *difficulties designing*. |
| | 12.3. gaps in program review mechanisms | | Gaps in the existing mechanisms for reviewing and assessing program decisions and deliverable output. |
| | | 12.3.1. insufficient peer reviewing | Insufficient peer reviewing and checking. Causal factor in Theme 2: *making mistakes*. |
| | | 12.3.2. lacking independent review | Lacking mechanism for assessing and scrutinizing the program by independent and unbiased reviewers, unchallenged program decisions. |
| | 12.4. low maturity full-scale program launch | | Launching into full-scale product development with low definition and low certainty, high-risk of downstream changes. Causal factor in Theme 17: *changing established plans, requirements*. |
| | | 12.4.1. insufficient preparatory technology development | Starting full-scale product development without sufficiently maturing readiness levels (RLs) and without enough data. Causal factor in Theme 1.1 *unanticipated design issues*. |
| | 12.5. unmethodical RL management and control | | Unmethodical management of design readiness levels (RLs) throughout development, not enough consideration. |
| | | 12.5.1. lacking RL assessment and control | Inadequate mechanism for evaluating, checking, or tracking RLs of the design throughout development contributing to a false sense of progress. |
| | | 12.5.2. progressing low RL designs late into development | Design readiness levels insufficiently matured before progressing the program into later phases. |

#### 4.2.1.14 *Limited past project learning*

Theme 13 captures a pattern of *some* successful project learning on the program albeit outweighed by missed opportunities thereof. The term *limited* was hence selected to best convey this pattern. As presented in Table 4.13 and Figure 4.14, the organization scheme for this thematic network is consequently delineated into two second-order themes. Theme 13.1 and Theme 13.2 respectively encompass instances of *missed* opportunities for project learning and instances of successful albeit *unsystematic* project learning. The former represents a contributing factor to Theme 2.3: *repeating mistakes*, whereas the latter represents a mitigating factor. The dual nature of this theme is conveyed through the ± symbol on the arrow connecting Theme 13 and 2 in the causal map of Figure 4.1.

Interestingly, Theme 13.1.4 makes reference to the same gap framed in Section 2.6 of the *Literature Review* which this research project contributes to addressing. Also, the relationship shared between Theme 13.2.1 as a mitigating factor in Theme 9: *uncertainty, difficulty predicting* is noteworthy as it captures the notion that successful project learning serves to reduce the level of uncertainty on a program. Ultimately, the unifying meaning of this theme is that there is still much untapped benefit to the greater organization that can be gained in this area.

Table 4.13: Thematic network summary of third-order Theme: *13. limited past project learning*

| Third-order theme | Second-order theme | First-order theme | Description |
|---|---|---|---|
| **13. limited past project learning** | | | Limited effort dedicated to past project learning, not fully benefiting from potential improvements to future program performance. |
| | 13.1. failing to learn from the past | | Failing to learn from experiences on former development programs, missing the opportunity to improve future program performance. |
| | | 13.1.1. old lessons not effectively transferred to new programs | Previously identified positive or negative experiences (lessons) on former programs not transferred to subsequent programs. Causal factor in Theme 2.3: *repeating mistakes*. |
| | | 13.1.2. neglecting to re-use, build on existing knowledge | Neglecting to re-use existing data and building on proven concepts from past projects. |
| | | 13.1.3. not seeking, following experienced-based advice | Not seeking or unreceptive to experience-based advice from experienced members of the organization ("grey-beards"). |
| | | 13.1.4. missing opportunity to improve company-level PD process | Missing the opportunity to learn from the fundamental failures and successes of different approaches (philosophies) to product development (PD) on past programs to inform and adapt the existing prescriptive company-level PD process. |
| | 13.2. unsystematic project learning | | Dedicating effort to learn from past programs on an ad-hoc basis. Mitigating factor in Theme 2.3. |
| | | 13.2.1. re-using, building on existing knowledge | Re-using existing data and improving proven concepts from past projects. Mitigating factor in Theme 9: *uncertainty, difficulty predicting*. |

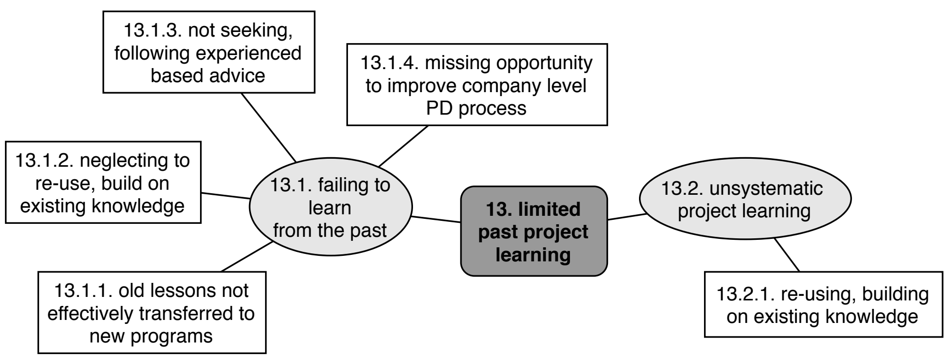


Figure 4.14: Thematic network illustration for third-order Theme: *13. limited past project learning*.

#### 4.2.1.15 *Inexperience, difficulty performing*

Theme 14 was abstracted to capture a straightforward pattern in the dataset pertaining to inexperience as an impediment to performance, present throughout multiple aspects of development. This theme represents a negative causal factor affecting the program and its organization is presented in Table 4.14 and Figure 4.15.

Second-order Theme 14.1 encompasses experience-based difficulties at multiple levels, including the levels of the company, teams, individuals, and suppliers. First-order Theme 14.1.1 is an interesting negative causal factor that underpinned the development. It captures that collectively the organization was inexperienced with the complexity and scope particular to clean sheet aircraft development as it had been a considerable number of years since the last program of that type. Inexperience at this level was found to have contributed to Themes 16.2.1 and 16.2.2. Second-order Theme 14.2 organizes difficulties experienced in navigating learning curves and specifies instances thereof. First-order Theme 14.2.2 is interesting as it captures the obvious causal relationship with Theme 1.2.4 in which inexperience contributed to the surprise of the increased effort necessitated in demonstrating compliance to some new certification regulation amendments.

Table 4.14: Thematic network summary of third-order Theme: *14. inexperience, difficulty performing.*

| Third-order theme | Second-order theme | First-order theme | Description |
|---|---|---|---|
| **14. inexperience, difficulty performing** | | | Inexperience as an obstacle to performing at the highest operational capacity. |
| | 14.1. multi-level experience-based challenges | | Encountering experience-based challenges at multiple levels of the organization. |
| | | 14.1.1. company inexperience, unfamiliarity executing | Collective organizational inexperience with clean sheet aircraft development, unaccustomed with the level of complexity and scope. Causal factor in Theme 16.2.1: *overoptimistic estimating, overpromising* and Theme 16.2.2: *understaffing program team, underallocating resources*. |
| | | 14.1.2. inexperienced practitioners, unconfident contributors | Practitioners inexperienced with clean sheet aircraft development, experiencing difficulty working confidently and autonomously, greater demand on leadership. Causal factor in Theme 7.1.2: *leadership overload, bottleneck*. |
| | | 14.1.3. inexperience working together, underperforming team | Inexperience working together as a team, undeveloped team chemistry, not performing at highest possible capacity. |
| | | 14.1.4. inexperienced suppliers, complications delivering | Subcontracting inexperienced suppliers, complications delivering and greater reliance on OEM for support. Causal factor in Theme 1.1.2: *substandard subcontractor work*. |
| | 14.2. complications mitigating learning curves | | Complications performing while getting accustomed to unfamiliar concepts. |
| | | 14.2.1. new software, low proficiency | Implementing new software tools, low proficiency among users. |
| | | 14.2.2. unfamiliarity satisfying latest certification regulation amendment | Unfamiliar with latest amendments of certification regulations, less than optimal approach to satisfying. Causal factor in Theme 1.2.4: *unexpected rigour meeting latest amendment level*. |

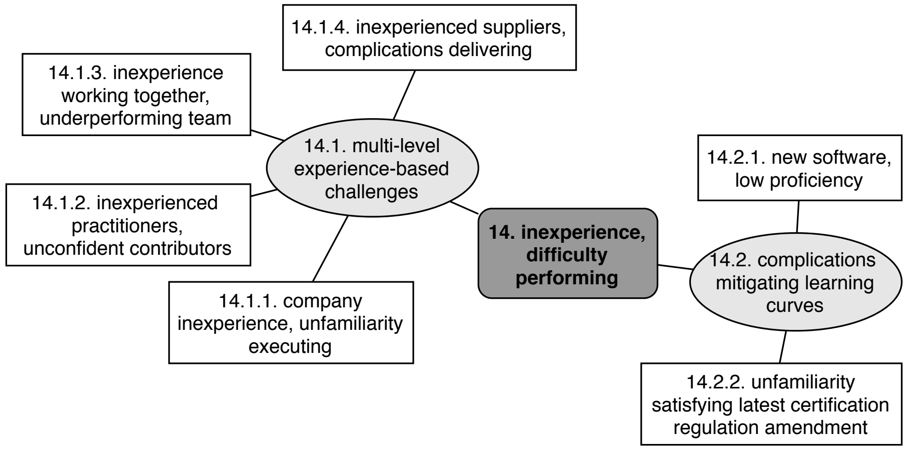


Figure 4.15: Thematic network illustration for third-order Theme: *14. inexperience, difficulty performing.*

#### 4.2.1.16 *Imperfect decision-making*

Theme 15 captures a pattern in the dataset regarding the decision-making process on the program not always yielding the optimal decision. In other words, it conveys that at times the decision-making process was fallible. This theme represents a negative causal factor affecting the program. Its categorization scheme is presented in Table 4.15 and Figure 4.16. Theme 15 is differentiated from Theme 2.2 in that the former centers on the process leading up to the decision whereas the latter centers on the decision itself and its consequential outcomes.

Second-order themes are delineated according to sources of fallibility in the decision-making process. Theme 15.1 organizes bias in the decision-making process and specifies instances thereof. First-order Theme 15.1.1 can be also be described as non-consensus decision-making. It involves an interesting causal relationship in which it was uncovered that this theme served to reinforce Theme 7.2.2: *growing practitioner frustration*. When considered independently, the relationship connecting these notions is obvious, however it serves as an example of a low visibility negative interplay, inconspicuously undermining the program. Theme 15.2 captures a pattern of making decisions without sufficient backup information. First-order Theme 15.2.1 specifies an instance of this on the program regarding novel decisions. It further nuances the concept by clarifying that for some decisions collecting supporting information was not always possible. In light of the greater theme, the imperfect decision-making process was thus attributable to both human fallibility and the inherent nature of some scenarios.

Table 4.15: Thematic network summary of third-order Theme: *15. imperfect decision-making.*

| Third-order theme | Second-order theme | First-order theme | Description |
|---|---|---|---|
| **15. imperfect decision-making** | | | Imperfect decision-making contributing to suboptimal decisions. Causal factor in Theme 17: *changing established plans, requirements* and Theme 2.2: *suboptimal decisions yielding negative outcomes.* |
| | 15.1. biased decision-making | | Decision-making susceptible to bias and influence, outcomes are directed and not optimally chosen. |
| | | 15.1.1. executive decision-making | Making decisions outright without consulting those impacted (for example, front-line practitioners). |
| | | 15.1.2. management pressure skewing outcomes | Outranking managers pressuring the outcome of decisions contrary to those recommended by subject-matter experts. |
| | 15.2. uninformed decision-making | | Making decisions without sufficient supporting evidence, based on assumptions and expectations. |
| | | 15.2.1. making novel decisions | No previous experience or knowledge to support the decision. |

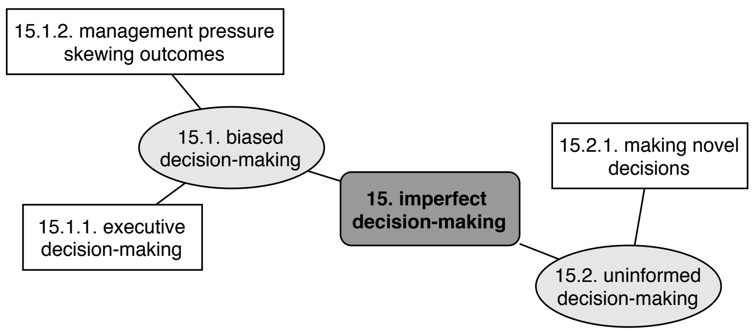


Figure 4.16: Thematic network illustration for third-order Theme: *15. imperfect decision-making.*

#### 4.2.1.17 *Problematic program planning*

Theme 16 was developed to capture a pattern in the dataset conveying that as an activity program planning was not only difficult to execute but also done at a low level of assurance. Hence, as per the title of this theme, program planning is designated as *problematic* in both meanings of the word: (i) difficult to execute and (ii) imbued with uncertainty. This theme represents a negative causal factor that affected the program and is organized as presented in Table 4.16 and Figure 4.17. It was abstracted from 3 distinct second-order themes which are delineated as follows.

First, Theme 16.1 captures the straightforward notion that a better effort could have been dedicated to planning the program. Second, Theme 16.2 encompasses sources of bias and inaccuracy that served to skew the planning process and specifies instances thereof. Nested first-order Theme 16.2.1 captures a pattern pertaining to a common unintentional bias in planning which was reported as being further perpetuated by *inexperience* (Theme 14.1.1). Also note that nested first-order Themes 16.2.1 and 16.2.2 are related in that the latter is a symptom of the former. As the development effort was underestimated (Theme 16.2.1), the number of resources consequentially allocated to the program was less than actually required (Theme 16.2.2).

Third, Theme 16.3 organizes a less obvious facet of planning that was experienced on the program and served to complicate the execution of the activity. The nested first-order themes specify some dimensions along which the program plan was negotiated and balanced as to satisfy competing requirements. In light of the greater program dynamic, Third-order Theme 16 provides some perspective into the program's baseline objectives (Theme 5).

Table 4.16: Thematic network summary of third-order Theme: *16. problematic program planning.*

| Third-order theme | Second-order theme | First-order theme | Description |
|---|---|---|---|
| **16. problematic program planning** | | | Difficult and uncertain execution of the program planning activity, undermining accuracy and achievability. Causal factor in Theme 5: *realistically unachievable initial objectives.* |
| | 16.1. lackluster planning effort | | Planning not given high priority, subpar effort. |
| | | 16.1.1. insufficiently supported | Execution of the planning process not well supported in terms of tools, opportunity for improvement. |
| | 16.2. planning biases & inaccuracies | | Biases and inaccuracies underlying planning, both deliberate and unintended. |
| | | 16.2.1. overoptimistic estimating, overpromising | Overoptimistic in ability to execute, underestimating effort needed to get work done and overpromising in planning. *Note that this theme parallels Theme 2.1.2: *misestimating, underestimating*. |
| | | 16.2.2. understaffing program team, underallocating resources | Not deploying enough contributors nor allocating enough resources to the program, symptomatic of overoptimistic estimating. Causal factor in Theme 7.1: *high demands on individuals, difficulty coping*. |
| | | 16.2.3. intentionally underrepresenting | Intentionally underrepresenting development efforts, for greater chance of securing program buy-in. |
| | 16.3. balancing competing ideals for program objectives | | Balancing competing ideals for program objectives among stakeholders at different levels in the organizational hierarchy. Senior leadership and front-line practitioners hold different perspectives with respect to planning. |
| | | 16.3.1. compromising on plans, an unavoidable reality | Compromising between 'wish-list' program plans and those financially viable for the organization is an unavoidable reality for program go-ahead. Aggressive but achievable planning. |
| | | 16.3.2. compressing program plan into limits of available resources | Compressing program plan to fit the limits of budget and time permissible as per the business opportunity and available company resources. |

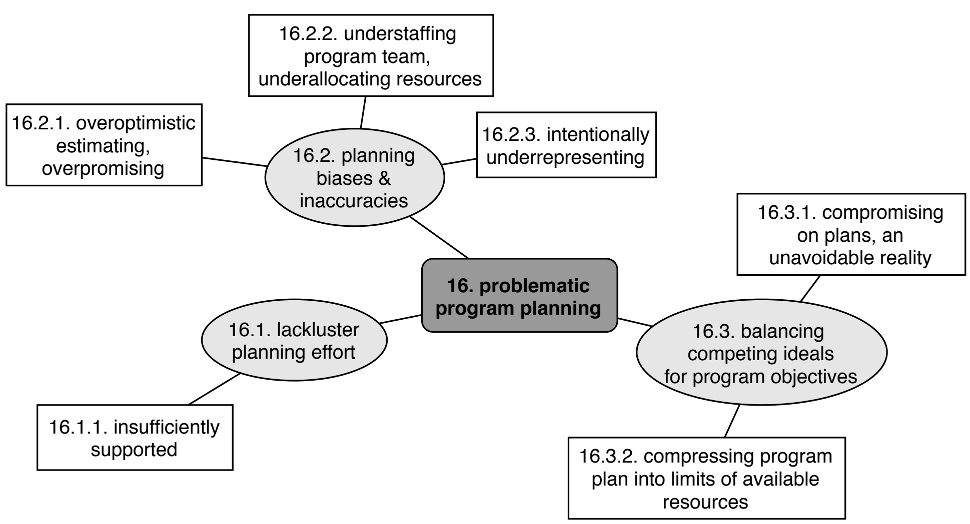


Figure 4.17: Thematic network illustration for third-order Theme: *16. problematic program planning.*

#### 4.2.1.18 *Changing established plans, requirements*

Theme 17 captures a pattern of established requirements and plans being changed as the development was already underway. This theme represents a negative causal factor affecting the program. As presented in Table 4.17 and Figure 4.18, it is organized into second-order themes along 2 dimensions of change: technical design requirements (Theme 17.1) and major program decisions (Theme 17.2). The first-order themes nested in each category specify instances of changes, however they were partially redacted given their sensitive nature.

This theme shares an interesting causal relationship with Theme 15.1.1: *executive decision-making* in which some respondents reported being on the receiving end of major changes without ever being consulted despite being directly impacted. Additionally, first-order Theme 17.2.1 captures a major program decision that was changed partway through development and the consequential driver of considerable rework (Theme 3). This change was motivated by an uncontrollable event and thus this theme shares a causal relationship with Theme 9.2.1: *unforeseeable, uncontrollable factors, 'acts of god'*. In the context of the greater theme, this conveys that unfavourable changes were sometimes inevitable and not deliberately motivated.

Table 4.17: Thematic network summary of third-order Theme: *17. changing established plans, requirements.*

| Third-order theme | Second-order theme | First-order theme | Description |
|---|---|---|---|
| **17. changing established plans, requirements** | | | Plans/requirements established at the program outset being changed partway through. Causal factor in Theme 3: *unforeseen, unplanned work, expenses, & delay*. |
| | 17.1. changing design requirements | | Changing 'frozen' technical design requirements. |
| | | 17.1.1. changing [redacted] requirement | Major [redacted] design requirement changed late in the program. |
| | 17.2. going back on major decisions | | Changing major program decisions. |
| | | 17.2.1. revising [redacted] | Decision on the [redacted] modified after work was already underway. Outcome of an unforeseeable event (Theme 9.2.1). |

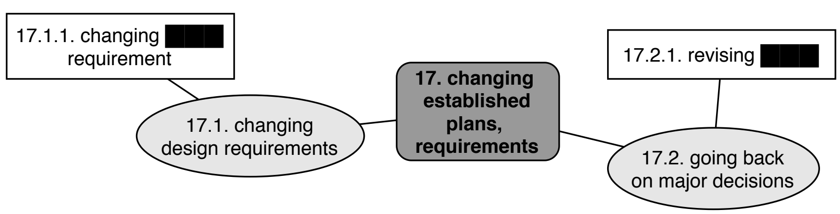


Figure 4.18: Thematic network illustration for third-order Theme: *17. changing established plans, requirements.*

## 4.3 Discussion of the results

This section provides a discussion of (i) the significance of the results of the case study and (ii) the significance of the research design itself, and (iii) the contribution of this work in light of the gap in the research literature is also covered.

### 4.3.1 Significance of themes and final causal map

The results indicate that no single root cause was responsible for the program's departure from its baseline objectives. As visualized by the causal map, the program's final outcome resulted from the nonobvious interplay among individual causal factors. A noteworthy implication of this complex program dynamic is such that impacts of actions and events occurring upstream in the development lifecycle or in isolation from other activities are propagated through the network as a result of causal linkages. As a consequence, seemingly innocuous actions or events have nonintuitive and indirect effects on the entirety of the program.

These results are in line with the research literature regarding drivers of cost and schedule overrun on complex development programs [65][88][89][90]. Given the broader motivation of this research project, of greater interest was the value that the identified themes and final causal map represent for the permanent organization. In the two following paragraphs, the value and importance of the analytic results for the organization are respectively demonstrated along two-dimensions: (i) as nonobvious, nontrivial lessons and (ii) as captured knowledge.

**(i)** The thematic networks and their constituent themes are a tiered catalogue of the drivers of success and failure affecting a PD development program undertaken in the context of *AeroCo*. That is, a collection of nonobvious and nontrivial lessons—i.e. experienced-based knowledge—pertaining to the execution of the organization's underlying PD process. Together with the causal map, they give a rich and organized account of the complex and nonintuitive narrative that was the development of the *Model I*, providing insight into *what* went "wrong", *what* went "right", and *how* these factors interacted.

**(ii)** Themes additionally have value as knowledge captured from disparate sources across the organization. In the qualitative data collection phase, various perspectives of the program were amalgamated into one cohesive dataset. Recounted experiences from numerous subject matter experts occupying different positions in the organizational hierarchy were combined to yield one conflicting, albeit partial, account of PD. The *data-driven* theme development process refined, ordered, and codified this unstructured and convoluted data into the themes organized in the tables above. Themes thus represent captured knowledge once residing in *AeroCo* employees.

These results represent a valuable resource for the host organization. *AeroCo* is now in a position to use this uncovered knowledge to begin assessing areas for improvement in their generic company-level PD process framework. Given the insight provided by the causal map, the opportunity is created for the organization to evaluate which specific interactions are the most impactful and pertinent for process improvement. Specific themes can then be evaluated based on how feasible or beneficial developing a response may be. Ultimately, this uncovered knowledge serves to empower the organization to make informed improvements in its processes.

As a final note, these genericized causal factors and the corresponding causal map can also be of interest to other commercial aircraft manufacturers and even organizations undertaking complex PD in unrelated industries. These results can bring light to similarly complex dynamics underlying other complex programs and help identify some of the same non-obvious interactions potentially affecting them. Furthermore, researchers interested in using similar qualitative methods for a similar application may leverage the conceptual framework established in this chapter. As a starting point for analyzing their own qualitative datasets, researchers can refer to the categorization system presented in Section 4.2. As such, researchers have the opportunity to take a *theoretical* approach to similarly-themed qualitative analyses instead of an *inductive* one like that outlined herein.[3]

### 4.3.2 Significance of the research design

The validated results presented in this chapter demonstrate that the mixed-methods research design formulated specifically for this case study *serves as a mechanism for analyzing and systematically identifying the root causes of a complex development program's outcome.* The mixed-method research design detailed in Chapter 3 and further described in Appendices A and B was a demonstrated means for:

(1) disaggregating a multiyear development program into manageable elements,
(2) strategically collecting data pertaining to the positive and negative aspects of the development program, and
(3) analyzing the dataset to distill and codify lessons pertaining to the fundamental successes and failures in the way the host organization executed its PD processes.

The effectiveness of the mixed-methods research design for untangling the behaviour of a complex development program was an unintended result of this research project. As noted in Chapter 1, the initial research motivation lent itself to the case study methodology.[4] Within this methodology, the researcher's choice of data collection and analysis methods was informed based on what was pragmatically feasible in the field. In this way, although the intention of this work was not to explicitly develop a means for identifying lessons on a complex development program, it was nevertheless an important outcome. The development and application of a unique research design for this specific application, can be considered as the overarching result of this study.

This overarching result—the mixed-methods research design as a mechanism for systematically uncovering root causes on a complex development program—is significant for a number of reasons. *First*, it represents a novel approach to a known difficulty. In order to untangle the complexity inherent to the development of the *Model I*, the researcher put together a unique combination of interdisciplinary research methods leveraging both quantitative and qualitative data. Notably, robust qualitative methods that are typically used in the social sciences were put into practice for this nontraditional application, i.e. to solve a "real world" engineering program management problem. In this way, the mixed-methods research design is unique but also rigorous and systematic given its foundation in established research methods.

*Second*, of noteworthy importance, the mixed-methods research design was implementable by a non-expert using only archived program documents and employee interviews. As validated by former program team members (see Section 3.8), the relatively inexperienced researcher was able to gain real insight into the high-complexity socio-technical endeavour using existing company resources. In this way, the mixed-methods research design is a relatively simple, unburdensome, and low-cost procedure for analyzing complex development programs and identifying lessons.

[3] See reference [72].

[4] The case study is described as a choice of *what* will be studied more so than a methodological choice [69, p. 40].

### 4.3.3 Significance of the overarching result in light of the gap in the literature

The broad need for research aimed at improving project learning in organizations executing complex programs was identified in the literature. More specifically, the need for more sophisticated project learning techniques capable of managing the complexity inherent to such programs was highlighted. This work addresses a particular aspect of that need which called for more effective mechanisms for untangling and identifying lessons. At the very least, it demonstrates that established qualitative research methodologies and methods can yield promising results for this atypical application. More substantially, the mixed-methods research design put forth herein is an effective and pragmatic approach for untangling and identifying lessons on complex programs. Note that although this approach was developed in the context of the aerospace industry, it is not strictly limited to complex development programs of this type.

In the broader context of this study—i.e. the ongoing improvement of generic PD processes—developing more robust means for learning from complex projects was important because the lack of adequate techniques for doing so was identified as a limiting factor preventing organizations from realizing the benefits of closed-loop feedback with respect to generic PD processes. The research design—that is the overarching result of this study—is an effort towards closing this gap. By providing an approach for analyzing and identifying lessons on complex programs, this contribution *is an enabler to* developing a full-fledged process for making closed-loop improvements to PD processes.

Empowering organizations to identify the fundamental successes and failures in the execution of their PD programs creates the opportunity for them to then leverage such knowledge for change and achieve true learning cycles. To illustrate the concept, the validation exercise of Section 3.8 is revisited in which some uncovered lessons were presented to former program team members. During this exercise, besides remarking several key lessons that had since been forgotten, this audience suggested how some lessons could be addressed by making changes to the organization's existing generic PD process framework. As such, this proposed mechanism can be *translated* and *extended* into a full-fledged process for making closed-loop improvements to PD processes. This is the subject of future work and further detailed in the corresponding Section 5.2.

## 4.4 Synthesis

- The outputs from the case study of the development program for the *Model I* were (i) a tiered catalogue of root causes driving the program's outcome and (ii) a map of their causal linkages.
- The causal map visualizes the significantly complex dynamic inherent to complex programs that makes it difficult to connect micro-level causes to macro-level outcomes and complicates learning.
- These outputs are lessons—i.e. experienced-based knowledge—–pertaining specifically to *AeroCo*'s product development process and the fundamental successes and failures of its actual execution.
- This uncovered knowledge represents a valuable resource for the host organization as it is in a position to make informed improvements in its generic company-level PD processes.
- These genericized causal factors and corresponding causal map can also be of interest to other organizations whose complex PD programs may be underpinned by a similar dynamic.
- The *overarching result* of this study is the research design itself as an effective mechanism

for analyzing and systematically identifying the root causes of a complex development program's outcome.

- This result is significant as it represents a novel approach to a known problem and has the advantages of being (i) rigorous and systematic as per its academic underpinnings, (ii) relatively simple to implement, and (iii) un-requiring of costly resources.
- This result advances the existing understanding of project learning techniques by demonstrating that concepts from the domain of qualitative research design can yield promising results for this nontraditional application.
- This result explicitly contributes to the need in the literature for more sophisticated organizational project learning tools and techniques.
- This result is an enabler to the *broader need* in the literature for techniques for realizing the closed-loop feedback of generic PD processes.

## 4.5 Chapter summary

This chapter presented the results of the case study: a catalogue of themes and a causal map of their interactions. Themes captured positive and negative causal factors that affected the development program for the *Model I* in achieving its objectives of schedule, cost, and quality. The causal map captured the causal linkages of these factors. These results were found to be of importance to the greater organization as lessons and captured knowledge of the fundamental successes and failures in the way products are developed specific to that context. In consequence, the unintended overarching result of this study was found to be the mixed-method research design itself as an effective mechanism for collecting and analyzing non-easily identifiable lessons of the root causes of a complex development program's outcome.

# Chapter 5

# Conclusion & Recommendations for future work

*In the fifth and final chapter of this thesis*, the reader is presented with a summary of this work and a synthesis of key results. Opportunities for continuing research are also presented.

## 5.1 Conclusion

### Summary of the research problem

Organizations invest substantial resources to implement generic product development (PD) processes as a means to manage the development of high-complexity products. Difficulties on recent aircraft development programs [6][7], however, suggest that manufacturers may not be fully benefiting from these tools. It was indicated in the literature that the mismatch between the claimed benefits of such generic PD processes and those observed in practice was attributable to their inadequate implementation [25][58]. Effectively adapting generic process models to match the organization's actual underlying processes, however, was shown to increase the likelihood of successful implementation [25]. It was argued in this thesis that organizations developing complex products could extract additional benefit from their experiences on former development programs to learn from and consequently adapt their generic PD processes.

### Summary of the gap in the existing research

Closed-loop PD process feedback is the concept whereby each completed development program represents a learning cycle through which improvements are made to existing generic PD processes. Although the benefit of this practice for ensuring the effectiveness and long-term use of PD processes is known, learning from projects in this way does not seem to be particularly successful in industry [17][27][28][29]. Organizations undertaking complex programs are limited in realizing the closed-loop feedback of their generic PD processes because of a lack of adequate learning techniques for this dedicated application. The limitations with project learning are multifaceted although the literature supports that there is a specific need for more sophisticated mechanisms for learning from complex programs. This includes robust and systematic means of untangling their counter-intuitive behaviour and identifying root causes of outcomes [17][27][30][31].

## Summary of the study, its contributions, and greater significance

This research project set out to investigate *why* aircraft development programs go over schedule in the context of a commercial manufacturer. A mixed-methods research design was developed and implemented for gaining new insight into this phenomenon. The case study was selected as the methodology, specifically, the single-case embedded design. The context of the study was *AeroCo*, a multinational commercial aircraft manufacturing company. The main case was the development program for a new architecture aircraft, the *Model I* development program. Two major program phases/activities embedded within this main case were selected as subunits for in-depth analysis.

Quantitative data was initially leveraged for strategically selecting the main case and embedded subunits. Subsequently, qualitative data was leveraged for explaining why the program overran its baseline schedule. Quantitative data was extracted from archived program documents in the form of dates and used to quantify schedule overrun. Qualitative data was collected through semi-structured interviews with former program team members. This textual data was then analyzed using an adapted form of thematic analysis (TA). This method was augmented using supplemental data reduction techniques from qualitative content analysis (QCA) and data display methods of thematic networks (TNs) and causal maps.

The results of the case study included (i) a tiered catalogue of root causes driving the program's outcome and (ii) a map of their causal linkages. In total, 17 thematic networks, representing 17 third-order themes, 48 second-order themes, and 86 first-order themes were developed. These uncovered themes are lessons pertaining specifically to *AeroCo*'s PD process and the fundamental successes and failures of its actual execution. The causal map visualizes the interactions among identified causal factors. It reflects the significantly complex dynamic inherent to complex programs that makes it difficult to connect micro-level causes to macro-level outcomes and complicates learning. Ultimately, these results represents a valuable resource for the host organization as it is in a better position to make informed improvements in its generic company-level PD processes. These genericized results can also be of interest to other organizations whose complex PD programs may be underpinned by a similar dynamic.

In response to the results of the case study, the mixed-methods research design itself emerged as the *overarching result* of this research project. Specifically, it was found to be an effective mechanism for analyzing a complex development program and systematically identifying the root causes of its outcome. The unique combination of academic research methods and nontraditional application was unexpectedly fruitful in confronting this known engineering program management difficulty. Furthermore, given its academic underpinnings and pragmatic-in-the-field development, this mechanism is (i) rigorous and systematic, (ii) relatively simple and unburdensome to implement, and (iii) does not require costly resources.

The overarching result of this study is an explicit contribution to the need for more sophisticated organizational project learning mechanisms specifically applicable to complex programs. Furthermore, by putting forth *an approach* for analyzing and identifying lessons on complex programs, this contribution *is an enabler to* developing a full-fledged process for making closed-loop improvements to PD processes. Future research is however needed to extend this proposed approach into a complete closed-loop feedback process.

In light of the research problem, this work establishes a path forward for organizations developing complex products to undertake the ongoing improvement of their existing PD processes by learning from past programs. In order for organizations to fully derive value from uncovered lessons, research is still required to "close" the feedback loop such that lessons can be leveraged into improvements for existing PD processes. The hope is that one day organizations may enjoy improved performance on future development programs because of enhancements in their generic PD processes informed through experiences on past development programs.

## 5.2 Recommendations for future work

This section lays out some directions for future research to continue addressing the research problem outlined in Subsection 1.3.

### ***Translating*** the mixed-methods research design into a practically usable process

As a recommended direction for continuing this research, it would be worthwhile to study the translation of the mechanism put forth in this thesis into an industry-oriented process for practical use in organizations. Additionally, it would be of interest to conduct a pilot application of this process in an organization responsible for developing complex products and directly involving the permanent employee base in its execution. Taking the project learning mechanism from an academic formulation to an operational process is a multifaceted endeavour and includes (i) rendering it more lightweight, as is discussed in the following paragraph, and (ii) tailoring it to the specific context of the individual organization.

The mixed-methods research design was specifically intended as a means of academic inquiry and was thus formulated to be rigorous and systematic as to ensure the production of trustworthy and credible results. For practical applications, producing valid results is still important, however, ensuring trustworthiness and credibility is not paramount. As such, it is proposed that the procedure defined in this thesis can be rendered more lightweight and thus practically usable by excluding some of the measures for achieving academic rigour. Specifically, a more "economical" process can be achieved by omitting the extensive and effortful checking and reviewing steps undertaken at multiple points in the data analysis procedure.

### ***Extending*** the mixed-methods research design into a full-fledged project learning process

As alluded to in Subsection 4.3.3, it is speculated that the mechanism defined in this thesis can be extended into a full-fledged process for realizing the closed-loop feedback of generic PD processes. From the perspective of the *project learning* literature (see Subsection 2.5.2), there are 3 components to general project learning processes: (i) collecting and identifying lessons, (ii) disseminating them, and (iii) implementing them for change. The mechanism defined in the body of this thesis was effective for achieving the *first* component: analyzing complex program behaviour and identifying lessons.

On the path to achieving a full-fledged process, more research is needed to develop a mechanism dedicated for "closing" the feedback loop. This entails formulating an approach for leveraging uncovered lessons to inform improvements in generic PD processes. It is proposed that developing these lessons into actionable improvements and integrating them into a centralized PD process framework is a means for storing and transferring uncovered knowledge to the permanent organization, thus achieving the *second* component of project learning. The *third* component, putting new knowledge into action, is theoretically achieved by future programs following the organization's enhanced PD process framework. By way of following enhanced models, such future programs may exhibit improved performance as per the model augmentations.

Conceptually, the mechanism put forth in this thesis *can* be extended into full-fledged project learning process for the specific application of improving generic PD processes. Practically, however, it poses a considerable challenge that would be the worthwhile subject of future research.

# Appendix A

# Research design: Literature review & Discussion

*In this appendix*, the reader is provided with (i) a review of academic research concepts in the domain of qualitative research, (ii) a review of traditional research designs in this area of study, and (iii) a discussion of this study's specific research design.

## A.1 Introduction

Before executing the study, considerable preliminary research was necessary for informing the development of a research design appropriate for the specific topic of investigation. *Qualitative* research designs are common in the domains overlapping this study's topic, including *organizational research* and *project management*. Qualitative research is traditional to the social sciences and encompasses a wide array of methodologies and methods. Given the researcher's background in the applied sciences, such concepts were mostly unfamiliar. This appendix provides a review of the fundamental qualitative research literature and a discussion of this study's research design from a theoretical perspective.

## A.2 Research designs: Paradigms, methodologies, and methods

This section reviews the concept of a *research design* and its constituent elements: the *research paradigm*, the *research methodology*, and the *research methods*.

### A.2.1 Research design

The *research design* is the unifying plan and procedure for meeting the research purpose that coherently and logically integrates a *research paradigm*, *research methodology*, and set of *research methods* [91, p. 5][92, p. 72]. Creswell [91, p. 3] notes that research designs can be positioned on a *qualitative—quantitative continuum* with *mixed-methods* residing in the middle. Historically, qualitative and quantitative research designs lent themselves to specific paradigms and vice versa, however in recent years mixed-methods have become more widely employed and accepted in various research paradigms [93, pp. 8-10]. The research purpose and/or question(s) under investigation, personal experience, and tradition guide the researcher to discern the most suitable selection of research design [91, pp. 18-19][93, pp. 5-8].

### A.2.2 Research paradigm

In conducting research, the fundamental assumptions and beliefs of the researcher ultimately impact how the study is undertaken, understood, and framed [92, p. 69]. These beliefs form a thinking framework that influences how a researcher sees the world, it is denoted the "research paradigm" [92, p. 69]. Creswell [91, pp. 5-6] alternatively refers to this concept as a "worldview". Authors Mackenzie and Knipe define the *research paradigm* as:

> "[...] 'a loose collection of logically related assumptions, concepts, or propositions that orient thinking and research' (Bogdan & Biklen 1998, p.22) or the philosophical intent or motivation for undertaking a study (Cohen & Manion 1994, p.38)" [93, p. 3].

The paradigms underpinning studies remain mostly implicit [91, p. 5][92, p. 69], although most authors agree that it is the fundamental basis for aligning the design of the entire study [92, p. 78][93, p. 10][94, Sec. 3.4]. There are a number of competing schools of thought regarding research paradigms as reviewed in references [91, pp. 5-11], [92], [93], and [95]. They can be distinguished along philosophical orientations of *epistemology* and *ontology*. The research paradigm informs the choice of appropriate *research methodology* and *methods*.

### A.2.3 Research methodology and methods

The *research methodology* and *research methods* are distinct concepts. Terms such as "research approach" and "strategy of inquiry"—Creswell's preferred denotation—are sometimes used interchangeably to refer to the *research methodology*. Creswell defines *strategies of inquiry* (*methodologies*) as:

> "[...] types of qualitative, quantitative, and mixed-methods designs or models that provide specific direction for procedures in a research design" [91, p. 11].

Many established methodologies are available to researchers of each type. In the framework of a research design, *research methods* put strategy (methodology) into practice [91, p. 11]. As defined by authors Mackenzie and Knipe, *research methods* are "[...] systematic modes, procedures or tools used for collection and analysis of data" [93, p. 6]. Wahyuni [92, p. 72] references an enriching analogy that likens the *research methodology* to a map, where *research methods* offer a means of travelling from one step to another on the map. This same author [92, p. 72] notes that research methods are a-theoretical, in that they are independent of any particular methodology or paradigm.

## A.3 Traditional research designs in this area of study

This section briefly reviews the research traditions found in the areas overlapping this study by (i)discussing the research designs observed from the Literature review in Chapter 2 and (ii) discussing a review by authors Bidenbach and Müller [96].

### A.3.1 Observations from the literature review

A number of research designs were observed in the published literature. The most prevalent methodology was that of the case study, with corresponding configurations varying according to the specific context of each study. Some studies were centred around in-depth single case investigations [97][98] and others examined multiple cases [11][19][43][57]. Additionally, some authors strictly dealt with qualitative data [28][62] whereas others leveraged a combination of both qualitative and quantitative data [17][66]. The methods of data collection that were observed in the review included practitioner interviews—mostly semi-structured—as well as practitioner surveys.

Ultimately, the flexibility afforded by the case study seems to lend itself to investigating the organizational contexts in real-world companies. The suitability of this methodology for researching product development (PD) processes in practical settings was even noted in reference [25, Ch. 3].

### A.3.2 Observations from Bidenbach and Müller (2010)

Bidenbach and Müller [96] reviewed project management research to study emerging research design trends in the domain. These authors found that "philosophical stances and the choice of research methodology are most often not explicitly expressed" [96, p. 83] in such studies. Both the project management and organizational research domains reported a multitude of active paradigms and methodologies. Interestingly, the case study was found to be the dominant methodological approach and research designs tended to be mostly qualitative. Bidenbach and Müller speculate the absence of explicit paradigmatic orientation can be attributed to a lack of awareness amongst authors of which a considerable number are practitioners who may not be familiar with such academic commitments.

## A.4 This study's research design

This section provides an explanation and discussion of the choices made regarding the specific design of this study. In the qualitative research landscape, especially concerning case studies [94, Sec. 4][99, pp. 2-3], transparency and clarity with respect to the design of the study is imperative for establishing the quality and trustworthiness of the research [92, pp. 76-78].

### A.4.1 Research paradigm

As the motivation for this work stemmed from industry, this study aimed to address an existing problem in a real-world environment. In this spirit, the research philosophy transcending the design of this study is from the *pragmatic* school of thought. The *pragmatic paradigm* or *worldview* focuses on what works best to solve the problem at hand rather than questioning epistemological and ontological commitments [92, p. 71]. In this paradigm, the research design is driven by the research purpose and/or question(s) under investigation and leverages any appropriate approach for understanding the problem [93, p. 5]. Research methods are selected based on their likelihood to be insightful and effective for meeting the research purpose above any philosophical loyalties [93, p. 5].

Authors in references [91, p. 10], [93, p. 5], and [100, p. 3] note that a distinguishing characteristic of pragmatism is that it makes no commitment "to any one system of philosophy and reality". Given its practical orientation, pragmatism lends itself to *mixed-methods research designs* [91, pp. 10-11][100, p. 3]. The paradigm gained support from mixed-methods researchers and has emerged as an important philosophical underpinning for such studies [93, p. 5][101, p. 1051]. For a broader examination of pragmatism, Morgan [102], a contemporary principal author in this topic, examines the evolution of pragmatism and discusses its essence as a paradigm.

This subsection represents a notable effort towards outlining the paradigm permeating this research.

## A.4.2 Research methodology

### A.4.2.1 Fundamentals of the case study methodological approach

The overarching research methodology or strategy of inquiry for this research was that of the *case study*. As noted by the authors in references [69, Ch. 3], [99], and [94, Sec. 3.2], the term *case study* is ambiguously and nonuniformly used in the literature. Merriam writes:

> "Part of the confusion surrounding case studies is that the process of conducting a case study is conflated with both [(i)] the unit of study (the case) and [(ii)] the product of this type of investigation." [69, p. 40].

Defining the case study as a methodological approach varies from one author to another given their particular orientation. A general and widely cited definition from Creswell et al. is referenced here:

> "Case study research is a qualitative approach in which the investigator explores a bounded system (a case) or multiple bounded systems (cases) over time through detailed, in-depth data collection involving multiple sources of information (e.g., observations, interviews, audiovisual material, and documents and reports) and reports a case description and case-based themes." [103, p. 245].

Fundamentally, the case study is an in-depth analysis of a bounded system in its real-life context to gain an understanding of its complexity [67, Ch. 1][69, Ch. 3][94][99].

There is existing debate among research methodologists regarding the credibility and integrity of the case study as a standalone methodology [94, Sec. 3.2]. As discussed by authors Hyett et al. [99] and Harrison et al. [94, Sec. 3.3], the case study provides a level of flexibility—i.e. creative freedom—which enables research designs to be tailored to the complexities of the specific case and research purpose. This advantage however has also provoked criticism as it has sometimes led to inconsistent application and lack of methodological rigour [67, p. 14]. Authors in references [94, Sec. 3.2] and [99, p. 9] highlight the importance of (i) providing sufficient detail in describing the design of the case study and (ii) following established approaches to maintain the integrity of the methodology.

There are a number of methodological approaches to the case study as discussed and reviewed in reference [94]. The case study approach taken in this research project was informed by the works of principal case study authors Merriam [69] and Yin [67]. Merriam's pragmatic approach was best suited for this study and more closely adhere to, whereas Yin's approach was used as additional guidance. Note that both these authors encourage the use of quantitative data to complement and enhance the focal qualitative investigation.

### A.4.2.2 Design of the case study

The research design of this study is typified as *mixed-methods*. On the qualitative—quantitative continuum it is positioned towards the qualitative end although not entirely. Quantitative data was initially collected and analyzed to inform the strategic selection of subunits for the more in-depth qualitative inquiry. This specific configuration is denoted as a "single-case embedded design" [67, pp. 46-53]. The *embedded design* identifies a sub-level of analysis embedded within the single main case. The components comprising this design are the context, main case (or “bounded system” [69, Ch. 3]), and subunits of analysis. This arrangement is illustrated in Figure A.1 as adapted from Yin [67, p. 46].

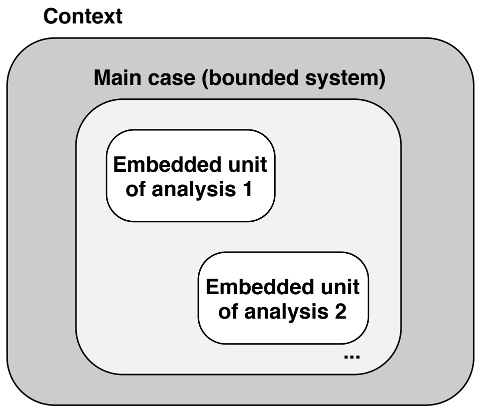


Figure A.1: Embedded single-case study design, adapted from Yin [67, p. 46].

The case study was well suited to meeting the research purpose. As noted in Chapters 1 and 2, aircraft development programs are highly complex socio-technical undertakings for reasons including non-intuitive project behaviour, multiyear development lifecycles, and high degrees of complexity. These characteristics make it difficult to trace outcomes of development programs to their root causes. The in-depth and flexible nature of case study research [69, p. 43] make it an appropriate methodological approach for confronting this difficulty and gaining insight into such programs. Moreover, the versatility to leverage different methods and types of data to “triangulate” [69, pp. 215-6] findings is particularly powerful for this application.

The decision to use a single-case design is justified, according to Yin [67, pp. 47-50], as the selected case is “representative” or “typical”. The development of a clean-sheet aircraft represents the typical execution of an organization’s product development process and the findings that can be drawn from investigating this case are insightful for the greater organization. An example from the literature is Dörfler and Baumann’s [97] case study centred on the single main case of the development program for the Airbus A380 as a means to examine organizational responses to program failure.

### A.4.3 Synthesis

The *research design* of this study was *mixed-methods*, however, the primary data source was *qualitative*. The underlying *research paradigm* was *pragmatism* and thus achieving the research purpose was the impetus for this framework. The selected *methodology* was the *case study* in the particular configuration of the *embedded single-case* design.

# Appendix B

# Worked examples from the qualitative analysis

*In this appendix*, the reader is presented with some worked examples from the actual application of the adapted analytic method described in Subsection 3.7.2 as to further clarify this aspect of the research project.

## B.1 Introduction

This appendix supplements Subsection 3.7.2 which outlined the analysis of qualitative data through application of the adapted analytic method. Some qualitative data analysis concepts presented therein are illustrated in the following examples, including (i) a case-based memo, (ii) code development, and (iii) within-case theme development. Examples were selected from the analysis of the interview transcript for Case 2 (C2 in Table 3.2). Given that these examples are of the earlier phases of analysis and thus subject to less processing, the data they contain is more specific. Therefore, some portions of text were redacted to protect sensitive information while minimally impacting the concepts they convey.

## B.2 The case-based memo

The case-based memo was not a product of the analytic method per se, however, it was an element developed for every case and it served to help the researcher initiate the within-case analysis. As such, the case-based memo generated after the Case 2 interview is provided as an example in Figure B.1. Note that it is a brief paragraph that captures pertinent respondent details, describes the general context of the exchange, and highlights interesting features of the interview.

## B.3 The coding process

The examples provided in Tables B.1 and B.2 illustrate how the researcher conducted *phase 3* of the within-case analysis process, which had the objective of processing data extracts into

**Case-based memo:** Interview with [redacted]

The participant was deployed to the development of the [redacted], specifically involved on [redacted].

From the start it was clear that the participant is very experienced and knowledgeable with respect to new product development programs. Standoffish at the start of the interview. Didn't have a clear understanding of my motivations and what I was after. Once provided with a better explanation of the motivation for the interview, the participant had no trouble giving an extensive account of his perception of the problems that caused schedule delay.

Some novel concepts stood out to me through the course of this interview, including the importance considering long supplier lead-times in [redacted] and the use of [redacted] for mitigating lead-times.

Figure B.1: Example of a case-based memo.

codes. These examples were taken from the actual within-case analysis of the Case 2 interview transcript. They demonstrate two typical coding units delineated by the researcher in *phase 2* of the within-case analysis. Note that the numbers assigned to each data extract—in these examples: coding unit #4 and #26—refer to their order in the transcript.

The researcher coded these data extracts (and the entirety of the dataset) by first working through the unit of text line by line and highlighting particularly salient words or phrases and crossing out non-content bearing text. The researcher then paraphrased the coding unit. As the coding units could encompass a considerable portion of text, paraphrasing was also done line by line and then concatenated upon completion. Although paraphrases were intended for expressing the coding unit in an abbreviated and standard style of writing, their ultimate intention as an intermediate product was to help with coding. The researcher thus sometimes prioritized the latter aspect of paraphrase development in place of a lesser word count.

After the paraphrasing activity, paraphrases were then further processed into codes. How segments of paraphrases were generalized is difficult to explicitly describe, however, it was helpful to continuously consider the question: "what is this (the paraphrase) an instance of?". Finalizing codes required the researcher to go back and forth between data extracts and codes to verify that the interpreted meaning captured by the code best represented the data extract.

Note that the finalized codes presented in these examples were particularly complex. Instead of breaking codes into smaller elements as in a labelling style of coding, complex codes were preferred as this format preserved more of the surrounding context. For both codes C2:4.1 and C2:26.1, their complex format enabled the researcher to capture causal relationships shared between elements of the code. As a consequence of developing complex codes, it was sometimes necessary to duplicate them in the subsequent thematizing phase given that they could be used to back more than one theme. The numbering scheme used to refer to specific codes was developed such that the researcher could identify the specific transcript and coding unit each code originated from. In cross-case thematizing, when codes from different cases were mixed, this numbering scheme was needed for maintaining traceability of the analysis.

Table B.1: Coding example 1.

| **Coding unit #4**[1] |
|---|
| [redacted] is just keeping very good regular communication while working ... the bigger the program ... the number of people working on it is epic ... if the communication is bad ... really good communication and not just flowing down... there's a lot of frustration when people start to feel nobody is listening to them... you have to tell them "I'm listening! ... and I understand what you're facing ... but these are the constraints that I have to deal with" ... and so its important to make sure that the team itself is aligned and doesn't get upset because they feel that the managers are ignoring the people who know what they're doing ... it's stuff like that, that can really impact programs ... it's all about listening to people ... communicate through the process ... |
| **Paraphrase** |
| Good regular communication is important, effective communication requires feedback: information flowing down (managers → front line practitioners) and back up (front-line practitioners → managers), important for making sure team is aligned and not frustrated, people get upset when nobody listens or provides feedback to their suggestions, impacts programs |
| **Code(s)** |
| • C2:4.1. Ineffective, one-way communication and lack of feedback causing frustration within the program team |

Table B.2: Coding example 2.

| **Coding unit #26**[2] |
|---|
| ... [redacted] testing schedule on the [redacted] was way off ... it's because there were some new things on there ... the novel [redacted] design... there were some efficiencies related with that design that were off, it didn't perform nearly as well ... once again ... doing development on a production program ... it was the first time doing a [redacted] design on a commercial aircraft ... not much experience ... they did their calculations ... but the actual performance they got out of it was lacking ... so that's why when you look at the [redacted] ... instead of restructuring the [redacted] ... so it's all that kind of stuff that comes along... |
| **Paraphrase** |
| Testing delays caused by novel [redacted] design, did not perform as expected. Integrating unconventional design, minimal experience. Required rework and [redacted]. |
| **Code(s)** |
| • C2:26.1. Unexpected design issue with the [redacted] design (minimal experience, unconventional design choice), causing rework, compromised design solution |

## B.4 Within-case thematizing

As a typical example representative of each of the 6 cases, this section provides the outputs from the final *phase 4* of the within-case analysis process for Case 2. Phase 4 was intended

[1]This extract from the Case 2 interview transcript was reworded for publication as to protect confidentiality.
[2]See footnote 1.

for developing candidate themes from codes and its final output included (i) a set of candidate themes—comprising working titles and descriptions—and (ii) a corresponding causal map. This section continues from where the previous section B.3 ended and illustrates how the researcher went about thematizing.

The multi-page Table B.3 comprehensively presents the multi-level set of candidate themes, their backing codes, and a description of each theme. In the table, codes are distinguished by the light-grey colour fill and they are organized such that the theme they are backing is presented in the adjacent row above. For example, Theme 1 *Establishing and disseminating robust requirements* was developed from Code C2:2.1 and Theme 9.2.1 *Difficulty predicting a/c flight characteristics* was developed from Codes C2:35.1 and C2:37.1. Themes without codes—for example, Theme 9.2—represent themes that were abstracted from more basic themes and serve to organize these lower-level themes. This was done in preparation for cross-case thematizing.

In the table, themes are categorized in content-related groups and according to the three levels of abstraction. For example, Theme 9 encompasses Theme 9.1 and 9.2, which further organizes Theme 9.2.1 and Theme 9.2.2. The numbers assigned to each theme were used for organizing the emerging categories, with main themes assigned *(X)*, nested sub-themes assigned *(X.Y)*, and double nested sub-sub-themes assigned *(X.Y.Z)*. Note that the set of candidate themes and corresponding categorization system presented in this table, were the *final* products of the within-case analysis for Case 2. The actual thematizing process was undertaken in a spreadsheet working file in which the researcher reworked the arrangement of codes, emerging themes, and categorization system, until a stable set of themes and categories was obtained.

Table B.3: Finalized results of the within-case thematizing for Case 2.

| Main theme | Sub-theme | Sub-sub-theme | Description |
|---|---|---|---|
| **1. Establishing and disseminating robust requirements** | | | Unambiguous and universally understood requirements are imperative for ensuring all units of the program team are aligned and progressing cohesively in the same direction. |
| • C2:2.1. Clearly identifying and universally disseminating requirements, allows for shared understanding and working towards them cohesively | | | |
| | 1.1 Forecasting market requirements | | Forecasting performance requirements to future market capability. The development timeline affords competition time to upgrade existing platforms. |
| • C2:3.1. Forecasting performance requirements to future market capability | | | |
| **2. Effective communication up and down CoC** | | | Information flowing through the organizational structure from the top-down but also from the bottom-up, promotes alignment and good morale |
| • C2:2.2. Good communication and regular feedback from design leads to ensure all units of the team are progressing in the same direction | | | |
| | 2.1 One-way communication, lack of feedback | | One-way communication or a lack of feedback to front-line practitioners makes people feel ignored and stems frustration. |
| • C2:4.1. Ineffective, one-way communication and lack of feedback causing frustration within the program team | | | |
| **3. Strong program team cohesion and alignment** | | | Fostering good team chemistry and keeping the different sub-teams aligned impacts the overall effectiveness of the program |
| • C2:2.1. Clearly identifying and universally disseminating requirements, allows for shared understanding and working towards them cohesively<br>• C2:2.2. Imperative for good communication and regular feedback from design leads to ensure all units of the team are progressing in the same direction | | | |
| **4. Involving CD's in the design process** | | | Including certification delegates in the design process helps ensure the product is certifiable as per the regulations. |
| • C2:5.1. Involving certification delegates in the design, streamlines the certification process and helps ensure the product is certifiable as per the regulations | | | |
| **5. Complications in the certification and validation** | | | Complications and obstacles in working with the agencies through the certification and validation process for the product. |
| • C2:6.1. —REDACTED—<br>• C2:10.1. —REDACTED—<br>• C2:12.1. —REDACTED—<br>• C2:13.2. —REDACTED— | | | |
| **6. Planned and measured approach to certification** | | | Working through the certification and validation process with the agencies following a thought out and measured approach to minimize risk of complication and obstacles. |
| | 6.1 Regular but careful communication | | Regular communication minimizes the risk of rework although involves a degree of measuredness. [redacted] |
| • C2:7.1. Communication between delegates and agency counterparts throughout the design and development process to minimize the risk of rework<br>• C2:7.2. —REDACTED—<br>• C2:13.1. —REDACTED— | | | |
| | 6.2 Managing delicate working relationships | | Delicate working relationships between the OEM and agencies complicated by personality conflicts |
| • C2:8.1. Relationship with the agencies complicated by personality conflicts at the individual level<br>• C2:15.1. —REDACTED—<br>• C2:33.1. Good cooperation between OEM and agencies expedited certification flight testing | | | |
| | 6.3 Appropriate certification and validation strategy | | Different strategies to certifying and validating the product exist, each with corresponding strengths and weaknesses. No proven 'successful' strategies. |

<table>
<tr><td colspan="4">• C2:9.1. Successful certification strategy in the past giving different results<br>• C2:10.1. —REDACTED—<br>• C2:12.1. —REDACTED—<br>• C2:13.2. —REDACTED—</td></tr>
<tr><td>7. Unrealistic baseline schedule</td><td></td><td></td><td>Initial schedule is not representative of real-life performance, realistically unachievable (mostly improbable).</td></tr>
<tr><td></td><td>7.1 Success oriented, no margin for error</td><td></td><td>Minimizing the schedule reserve (buffer) used to mitigate uncertainties as a result of external pressure.</td></tr>
<tr><td colspan="4">• C2:16.1. Unrealistic schedules to get program go ahead, success oriented and no margin for error<br>• C2:21.3. Evolving technology during product developments needs sufficient schedule buffer to mitigate high risk and develop the supply chain<br>• C2:35.2. Unknown unknowns, mitigated using schedule buffer, management pressure to eliminate</td></tr>
<tr><td>9. Uncertainty, unpredictability</td><td></td><td></td><td>Incomplete information and limits to the ability to predict outcomes.</td></tr>
<tr><td></td><td>9.1 Limited visibility scheduling</td><td></td><td>Incomplete knowledge of the PD process leads to complications developing the schedule.</td></tr>
<tr><td colspan="4">• C2:17.1 Difficulty scheduling, development uncertainty and unknown unknown's<br>• C2:35.1. Difficulty scheduling flight test program, there will always be unknowns, models will always have inaccuracies</td></tr>
<tr><td></td><td>9.2 At risk a/c systems</td><td></td><td>Difficulty predicting the behaviour of some a/c systems is the root of some unexpected design issues.</td></tr>
<tr><td></td><td></td><td>9.2.1 Difficulty predicting a/c flight characteristics.</td><td>Flight characteristics and behaviour of the a/c are to a degree unpredictable resulting in unexpected design issues during flight testing. Modelling capabilities are imperfect. Results in unavoidable rework.</td></tr>
<tr><td colspan="4">• C2:35.1. Difficulty scheduling flight test program, will always be unknowns, models will always have inaccuracies<br>• C2:37.1. Modelling and predicting [redacted] performance, highly complex</td></tr>
<tr><td></td><td></td><td>9.2.2 Historically problematic systems</td><td>Across platforms some systems are recurrently difficult to predict and historically the cause of unexpected design issues.</td></tr>
<tr><td colspan="4">• C2:27.1. Unexpected design issue with historically problematic system, causing rework<br>• C2:31.1. Recurring (historically problematic) technical issues across platforms, questions [redacted] and modelling capabilities (for example, [redacted])</td></tr>
<tr><td>10. Unforeseen and unplanned work, expenses, and lead times</td><td></td><td></td><td>Additional work tasks, activities, and lead times not initially planned for.</td></tr>
<tr><td colspan="4">• C2:18.2. Unforeseen time spent optimizing the supply chain</td></tr>
<tr><td></td><td>10.1 correcting issues, rework</td><td></td><td>Unwanted and unfortunate iteration to correct an issue</td></tr>
<tr><td colspan="4">• C2:19.1/20.1/21.2 Developing and incorporating low maturity (TRL & MRL) concepts in the design, high risk of unexpected design issues, requiring rework<br>• C2:25.3 high risk, unconventional design decision, unexpected design issue uncovered in flight testing, rework, compromised design solution<br>• C2:25.4 Reworking the design generates compromised solutions (expensive and by no means optimized) and delay<br>• C2:26.1. Unexpected design issue with the [redacted] design (minimal experience, unconventional design choice), causing rework, compromised design solution<br>• C2:27.1. Unexpected design issue with historically problematic system, causing rework<br>• C2:29.1 Troubleshooting, redesigning, and waiting for production representative parts causing downtime</td></tr>
<tr><td></td><td>10.2 Downtime, waiting on lead times</td><td></td><td>Putting an activity on hold because of a lead time.</td></tr>
<tr><td colspan="4">• C2:18.1. Mistaking the estimate for critical component lead time, waiting for parts<br>• C2:29.1 Troubleshooting, redesigning, and waiting for production representative parts causing downtime</td></tr>
<tr><td>11. High-risk decision-making</td><td></td><td></td><td>Making decisions that expose the program to high-risk.</td></tr>
<tr><td></td><td>11.1 Incorporating low maturity (TRL & MRL) concepts</td><td></td><td>Including in the design new technologies with low levels of maturity (TRL & MRL). Alternatively put, developing new technology concurrently to product development.</td></tr>
<tr><td colspan="4">• C2:19.1/20.1/21.2 Developing and incorporating low maturity (TRL & MRL) concepts in the design, high risk of unexpected design issues, requiring rework<br>• C2:36.1. Developing new technology concurrent to PD, drives schedule increase</td></tr>
</table>

| | | | |
|---|---|---|---|
| | 11.2 Incorporating unconventional design concepts | | Including in the design established concepts that the organization has minimal experience with. |
| • C2:19.1/20.1/21.2 Developing and incorporating low maturity (TRL & MRL) concepts in the design, high risk of unexpected design issues, requiring rework<br>• C2:25.3 high risk, unconventional design decision, unexpected design issue uncovered in flight testing, rework, compromised design solution<br>• C2:26.1. Unexpected design issue with the [redacted] design (minimal experience, unconventional design choice), causing rework, compromised design solution | | | |
| | 11.3 Foregoing provisions for risk mitigation | | Making high risk decisions without putting in place measures for mitigation in scenarios where risks materialize. |
| • C2:25.2. Taking high risk design decisions without provisions for mitigation (for example, [redacted]) | | | |
| **12. Unfavourable outcomes** | | | Completing programs activities/deliverables with less than desirable results either necessitating rework or unnecessarily driving up costs and lead times. |
| | 12.1 Unexpected design issues | | Unanticipated issues with the design necessitating rework. |
| | | 12.1.1 Finding surprises during flight testing | Flight testing inevitably uncovering issues with the design (Discovering unknown unknowns) |
| • C2:19.1/20.1/21.2 Developing and incorporating low maturity (TRL & MRL) concepts in the design, high risk of unexpected design issues, requiring rework<br>• C2:25.3 high risk, unconventional design decision, unexpected design issue uncovered in flight testing, rework, compromised design solution<br>• C2:26.1. Unexpected design issue with the [redacted] design (minimal experience, unconventional design choice), causing rework, compromised design solution<br>• C2:27.1. Unexpected design issue with historically problematic system, causing rework<br>• C2:29.2. Finding surprises during flight testing | | | |
| | 12.2 Less than optimal designs | | Designing acceptable components although at unreasonably high costs and excessive lead times. |
| | | 12.2.1 Choosing inappropriate design tolerances | Choosing tolerances for components that don't match the application, either overly stringent or too loose. |
| • C2:23.1. Selecting inappropriate design tolerances drive cost and turnaround time up | | | |
| | | 12.2.2 Neglecting manufacturability | Neglecting to optimize designs for ease of manufacturability. |
| • C2:22.1. Neglecting ease of manufacturability, driving up cost and turnaround time | | | |
| | 12.3 Making mistakes | | Improperly completing an activity or task necessitating corrective rework or additional expense. |
| | | 12.3.1 Underestimating | Underestimating work efforts, costs, and lead times. |
| • C2:18.1. Mistaking the estimate for critical component lead time, waiting for parts<br>• C2:30.1. Underestimating effort to solve [redacted] issues, intervention took longer than expected<br>• C2:32.1. Underestimating effort to solve [redacted] issues, intervention took longer than expected | | | |
| | | 12.3.2 Repeating | Repeating mistakes already made before. |
| • C2:21.1. [redacted] does a poor job learning from the past, causes repeating of mistakes | | | |
| 13. Factors skewing the decision-making process | | | Factors external to the decision-making process influencing outcomes. |
| | 13.1 Uniformed mgmt pressure | | Outranking managers pressuring decisions in spite of expert opinion. |
| • C2:19.2. Management putting pressure on program decisions<br>• C2:28.1. Troubleshooting complicated by an uniformed management decision<br>• C2:35.2. Unknown unknowns, mitigated using schedule buffer, management pressure to eliminate | | | |

| | | | |
|---|---|---|---|
| 14. Checking and reviewing | | | Lacking reviewing mechanisms for mitigating preventable unfavourable outcomes from materializing. |
| • C2:23.2: Not enough checking/reviewing design details from a top-level to mitigate design issues | | | |
| 15. Not learning from the past | | | Lessons previously identified not transferred nor leveraged on current program. |
| • C2:21.1. [redacted] does a poor job learning from the past, causes repeating of mistakes | | | |
| | 15.1 Not following experienced advice | | Program team unreceptive to experience-based feedback. |
| • C2:25.1. Not listening to advice from experienced subject matter experts<br>• C2:25.5. Getting feedback from experienced engineers could be improved | | | |
| 16. Implementing risk reducing activities | | | Up-front activities aimed at maturing both the design and readiness levels as early as possible |
| | 16.1 Bolstering modelling capabilities | | Investing in higher fidelity and more robust modelling tools to better predict a/c behaviour and reduce risk of flight test surprises. |
| • C2:31.1. Recurring (historically problematic) technical issues across platforms, questions [redacted] and modelling capabilities (for example, [redacted]) | | | |
| | 16.2 Concept demonstrator testing | | Upfront testing of historically problematic systems to reduce uncertainty and risk of rework. |
| • C2:27.2. Upfront concept demonstrator testing to mature historically problematic systems/components | | | |
| 17. Effective flight-testing strategy | | | Specific methodology guiding experimental flight testing for the [redacted] was effective for expediting the activity. |
| • C2:34.1. Followed an effective [redacted] flight test strategy, minimized downtime | | | |

The causal map developed as part of this within-case analysis is presented in Figure B.2. It is also pictured in the top left corner of Figure 3.8 where it was used for cross-case thematizing. The map illustrates the causal relationships among main themes which are indicated by the rounded rectangles. The relationships between main themes were developed based on those captured by the codes. Sub-themes are also represented in the causal map as ovals linked to their main themes. Causal maps were progressively formulated. As a theme was developed, it was immediately visualized in the map along with any associated relationships. The causal map presented in this figure was the fourth iteration developed for the Case 2 analysis.

[redacted]-CAUSAL-MAP-REV4

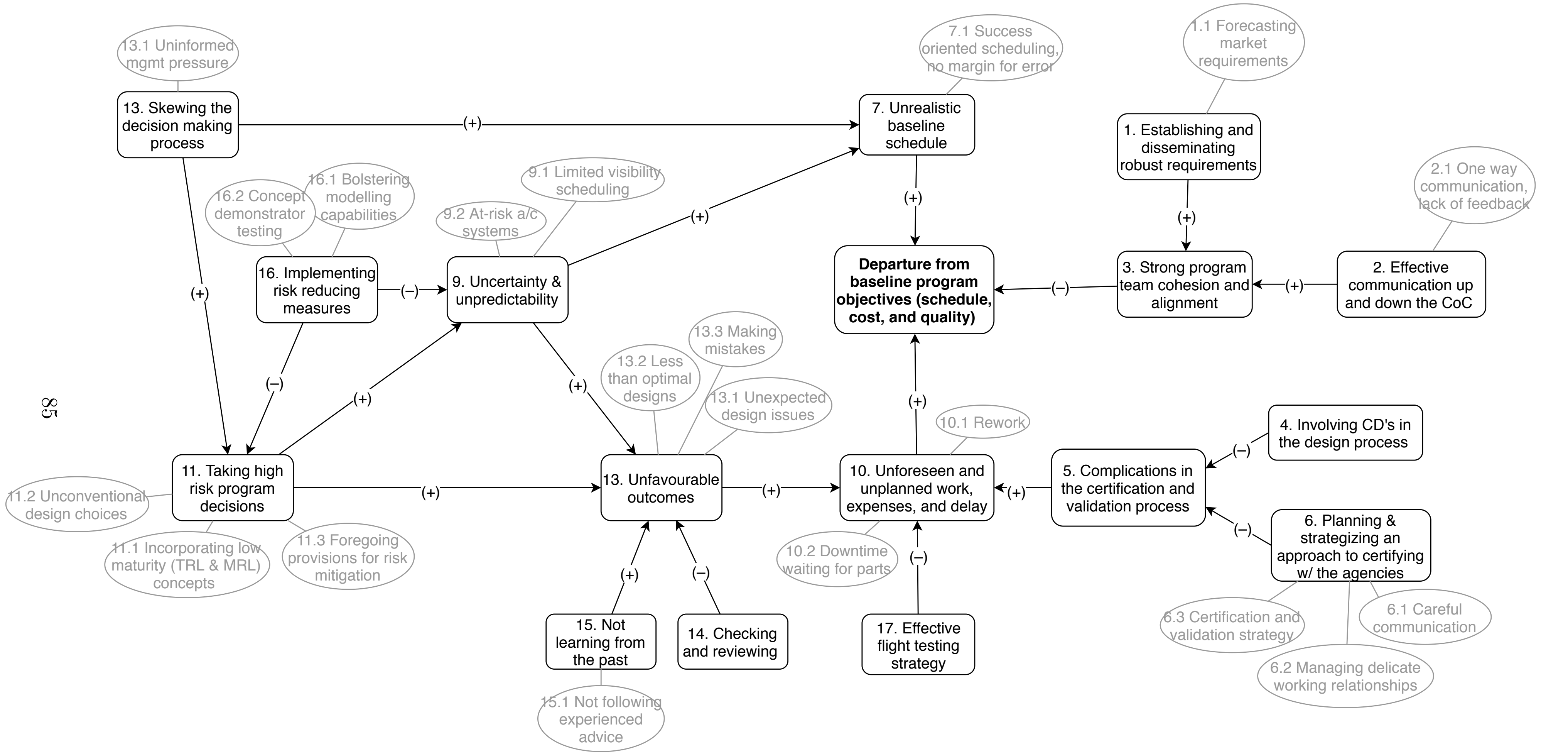


Figure B.2: Causal map illustrating the cause and effect relationships among main candidate themes developed for the within-case analysis of Case 2.

### B.4.1 Synthesis

The intermediate products of analysis presented in this section were the outputs of just one of six within-case analyses. These result tables and causal maps were the groundwork for the cross-case analyses, where these findings were subsequently pooled together, arranged, and further processed.

## B.5 Cross-case thematizing

As a means for clarifying cross-case thematizing for the reader, Table B.4 provides an excerpt of the finalized thematic network originally presented in Table 4.2. This excerpt features the codes backing first-order Themes 2.1.1 and 2.1.2, they are collated in the adjacent rows directly below each of these themes. Note how codes from across several different cases (C2, C11, C16, and C18) were sorted and arranged to provide the backing for these themes. Second-order Theme 2.1 was abstracted to encompass and organize these basic themes. Third-order Theme 2 was further abstracted to capture the unifying meaning, central to each of these constituent themes (including those not pictured here). Theme 2 *making mistakes* represents a fundamental meaning-based pattern in the dataset.

Table B.4: Excerpt from the thematic network for third-order Theme: 2. *making mistakes*

<table>
<tr><th>Third-order theme</th><th>Second-order theme</th><th>First-order theme</th><th>Description</th></tr>
<tr><td>2. making mistakes</td><td></td><td></td><td>Doing something incorrectly (misguided judgments and actions), resulting in Theme 1: unexpected complications, undesirable outcomes, Theme 3: unforeseen, unplanned work, expenses, and delay, and Theme 4: less than fully optimized final design.</td></tr>
<tr><td></td><td>2.1. necessary but misguided decisions</td><td></td><td>Necessary decisions made in the face of incomplete information that were ultimately mistaken.</td></tr>
<tr><td></td><td></td><td>2.1.1. false assumptions & expectations</td><td>Assumptions and expectations used for drawing conclusions believed to be true although actually incorrect.</td></tr>
<tr><td colspan="4">• C18:31.1. Belief subcontracting [redacted] save costs, ultimately too expensive for the program to absorb<br>• C18:22.2. Subcontracting inexperienced [redacted] was longer, more expensive and low quality outcome<br>• C16:7.2. Senior management expectations for showing compliance based on uninformed assumptions, did not materialize<br>• C11:25.1. mistaken assumption of the [redacted] driven by unpredictable [redacted]<br>• C11:34.2. mistaken assumption driving program requirements, resulting in an unnecessarily complex and expensive design</td></tr>
<tr><td></td><td></td><td>2.1.2. misestimating, underestimating</td><td>Improperly approximating real-life parameters, values, and magnitudes. For example, costs, efforts, lead times...</td></tr>
<tr><td colspan="4">• C2:18.1. Mistaking the estimate for critical component lead time, waiting for parts<br>• C2:30.1. Underestimating effort to solve [redacted] issues, intervention took longer than expected<br>• C2:32.1. Underestimating effort to solve [redacted] issues, intervention took longer than expected<br>• C16:12.1. Underestimating, resulting in a lack of effort and poor quality (e.g. [redacted])</td></tr>
</table>

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