Process Mapping for Interdisciplinary Aerospace Processes: A Case Study

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Abstract

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Karine Gosselin

The multidisciplinary nature of aerospace processes demands coordination across diverse functions, each contributing to the design, development, sustainment, and compliance of highly regulated aerospace products. These processes involve various interconnected and interdependent elements that influence execution, making it challenging to fully deconstruct and reveal the underlying complexities and interactions that shape the overall process.

This thesis explores a practical adaptation of a process mapping technique within the aerospace industry, focusing on a single case study at a Canadian aircraft maintenance company. Through this case study, the thesis illustrates how multiple process mapping approaches can offer different perspectives and enhance process transparency. A current-state manufacturing process is mapped at five different levels of detail: Level 1 provides a high-level overview of the process with milestones and principal tasks; Level 2 incorporates information flow through artifact types; Level 3 adds the roles and expertise required for each activity in the process; Level 4 introduces communication activities; and Level 5 details the working time for each activity.

By analyzing the results from each mapping level, the study evaluates the usability and benefits of incorporating different process elements. The findings show that process mapping is not only suitable for visualizing task-specific workflow but can be customized to meet other end-user needs. It was found that no single level of detail is entirely self-sufficient, and that combining elements such as information flow, roles, communication and time provides distinct perspectives offering value across a wide range of use cases and objectives.

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Table of Contents

List of Figures

List of Tables

List of Acronyms

AME	Aircraft Maintenance Engineer
AMO	Aircraft Maintenance Organization
BPMN	Business Process Mapping Notation
ERP	Enterprise Resource Planning
ESR	Engineering Support Request
ESRF	Engineering Support Request Form
ICAO	International Civil Aviation Organization
ID	Identification
IDEF0	Icam DEFinition for Function Modeling
ISM	Information Systems Modeling
IT	Information Technology
MRF	Minor Repair Form
MRO	Maintenance, Repair, and Overhaul
NRIF	New Repair Instructions Form
OEM	Original Equipment Manufacturer
PDF	Portable Document Format
PLM	Product Lifecycle Management
SME	Subject Matter Expert
UML	Unified Modeling Language

Chapter 1. Introduction

The aerospace industry is characterized by its complex, multidisciplinary nature [1], [2], requiring reliable and effective collaboration and communication among all parties involved in aircraft design, development, manufacturing, production, and maintenance [2]. The realization of an aerospace product requires coordination across various departments, stakeholders, regulatory bodies and external partners. Additionally, the wide range of requirements – spanning functional needs, cross-disciplinary integration with potentially competing objectives, and complying with airworthiness standards and regulations – requires effective management and integration throughout all phases of the product lifecycle [3]. The complexities surrounding the aerospace product itself, combined with the effectiveness of collaboration and communication activities, can lead to delays and errors [4], [5], [6], [7].

The drive to reduce costs and improve productivity has led to the exploration and implementation of new methods, technologies, and practices. However, developing, modifying, or improving existing processes is challenging due to the many interconnected elements involved. Processes can be viewed at various levels of detail, from high-level overviews to task-specific workflows. Identifying opportunities for improvement or designing an ideal state process requires a clear view of the process itself and a structured method for capturing the influential elements involved. Given the interconnected nature of these elements, it can be difficult to determine how each part affects the overall process. A comprehensive understanding of these elements can enhance process performance and management, improve collaboration and communication [8], [9], [10], and enable the identification of areas for improvement [11], [12].

A typical aerospace process not only consists of steps or activities, but also includes actors' various roles in executing them. Furthermore, the flow and transformation of information through various artifact types must be effectively managed and traceable to ensure compliance with airworthiness standards and regulations [7]. Interactions and communication, both within and across departments, such as hand-offs and collaborative activities – can directly influence process outcomes [8], [9], [10], [13]. Finally, the time required to execute each step may vary depending on the process structure, decisions made, and resource availability, further influencing the overall process efficiency.

Process mapping is one method that provides a structured approach to visualizing and analyzing workflows within an organization. By offering a visual representation of the sequence of activities in a process, a process map shows how work is performed. Mapping complex, multidisciplinary processes, such as those commonly found in aerospace, introduces additional challenges. The involvement of multiple functions and the range of influential elements associated with aerospace processes can result in the inability of traditional process mapping techniques to capture the full complexity of these workflows.

This thesis explores the use of process mapping as a method for better capturing and understanding processes within the aerospace industry. Using a case study, the research investigates the application of different levels of detail in a process map and examines the value each level brings to process map users and stakeholders. The case study focuses on a single multidisciplinary manufacturing process at a Canadian maintenance, repair & overhaul (MRO) aircraft organization. The process is mapped at varying levels of detail to illustrate different perspectives of the workflow. Each map reveals unique insights into the process, offering stakeholders a tailored view that may be required/useful for specific needs and objectives.

The research is guided by several key questions such as: How can these different factors or elements be shown on a process map? Does including these different perspectives provide additional information that wouldn't typically be available from a task-focused process map? What levels of process mapping detail are most useful for specific roles or purposes? By addressing these questions, this thesis seeks to demonstrate the value of process mapping as a strategic tool for understanding workplace process in the aerospace industry, with implications for other complex, multidisciplinary fields.

This research contributes to the understanding of how process mapping can be adapted and applied to meet the specific needs of stakeholders in the aerospace industry. By focusing on a single case study, the thesis provides detailed insights into the practical application of various mapping techniques and highlights the value of what is revealed at each level of detail.

This thesis is structured into chapters, beginning with Chapter 1, serving as the introduction. Chapter 2 reviews the literature relevant to this research, addressing topics such as complexity in aerospace, collaboration and communication in multidisciplinary processes, the importance of understanding workplace processes, the use of process mapping techniques, and case studies. Chapter 3 outlines the research objectives and the specific questions to be addressed. The methodology used to gather data and develop the process maps is detailed in Chapter 4. Chapter 5 presents the results and discusses the observations derived from each level of detail. Finally, Chapter 6 concludes the thesis and offers recommendations for future research.

Chapter 2. Literature Review

2.1. Complexity in aerospace

The aerospace product is a system-of-systems where sub-systems and components [1], [2] are often inter-dependent and require expert integration to meet performance targets [14], [15]. The design, manufacturing and maintenance of the aerospace product requires a diversity of knowledge and skills [3], [16], and aircraft developers employ experts from a variety of disciplines, resulting in the need for carefully managed inter-disciplinary activity throughout all phases of the product lifecycle [3].

The complexity of the aircraft production environment is made more challenging by the requirement to comply with airworthiness regulations, national security and export control laws [17], [18], [19]. The aerospace industry is bound by global standards maintained by the International Civil Aviation Organization (ICAO) and by regulations established by airworthiness authorities designated in each country [18]. Airworthiness standards govern all phases of an aeronautical product including design, production, and maintenance; and are accompanied by advisory or mandatory techniques and methodologies to ensure product safety and quality [20], [21].

In the aerospace industry, traceability, information and requirements management are particularly challenging due to the large amounts of data that needs to be traced. Researchers in the field have recognized these challenges, and recent research includes studies aimed at mitigating the complexities inherent in traceability, information management, and requirements management [21], [22], [23], [24]**.** Efforts have been directed toward developing advanced tools, software systems, and methodologies to streamline processes [24], however challenges still exist with their implementation, integration, interoperability, and data security [25], [26], [27], [28], [29].

2.2. Collaboration

The aerospace industry increasingly relies on collaborations to facilitate the exchange of knowledge and resources [30] and the sharing of risks and costs [31]. Collaborative networks often extend beyond the main firms engaged in product design and development to include contributing partners in manufacturing and assembly, as well as suppliers and sub-suppliers producing subsystems and components [31], [32]. Chu et al. [5] emphasize the need for efficient collaboration among manufacturing sectors in order to shorten lead times and improve product quality. In other research, Morton et al. [8] recognize the importance of collaboration within and between product development organizations; emphasizing the need to understand the relationships between teams, departments, organizations, and suppliers. The quality of collaboration affects project timeline, cost, innovation and productivity [6]. The importance of collaboration in the aerospace industry has prompted an exploration of factors influencing collaboration efforts. Baalbergen et al. [33] have categorized potential barriers between aerospace engineers into three broad levels; organizational, human, and technical.

2.2.1. Organizational-level barriers

Organizational-level barriers stem from the need to protect resources and property, resulting in intricate security policies that complicate the exchange of information [33]. Organizational-level barriers mentioned by other researchers include organizational silos [34], [35], referring to the presence of barriers between subgroups, functional groups, or departments. Despite slight variations on silo characterization [34], [36], [37], the literature consistently represents silos as a process barrier that hinders the coordination and productivity of employees. According to Tett, silos are essential to create a structure to manage the complexity of the modern world, however, they can also lead to tunnel vision, and isolated departments or teams failing to communicate [38].

Organizational silos can also be a result of the physical distance and locations of team members. The expansion of aerospace organizations and the growing product complexity necessitate acquiring additional expertise and implementing a hierarchical distribution of work, resulting in the geographical dispersion of personnel and departments [39]. This geographical dispersal of employees is also seen as a barrier preventing effective collaboration [40]. Numerous studies [4], [39], [41], [42] explore strategies to facilitate collaboration among geographically dispersed teams, and are often focused on the development of software tools and resources.

2.2.2. Human-level barriers

According to [33], human-level collaboration barriers arise from factors such as cultural differences, variations in languages and terminology used between different disciplines, lack of trust, resistance to collaborative-supporting changes, and inadequate knowledge sharing. Also seen as an *intercultural collaboration* problem is the use of different languages and terminologies for identical meanings or representations [43]. Common among professionals with different knowledge backgrounds, language and semantic barriers can lead to misunderstandings or misinterpretations [44]. In a study at an engineering firm specializing in complex systems, Meluso et al. [45] determined that the term "estimate" was interpreted differently by engineering practitioners. This variation led to communication errors, subsequently impacting system performance. Collaboration between different domains requires actors to manage, share and assess specialized knowledge across various types of boundaries through the use of common knowledge [46]. Effectively managing multidisciplinary knowledge requires acknowledging potential variations in language and terminologies and establishing a common vocabulary to mitigate the risks of miscommunication.

2.2.3. Technical-level barriers

Technical-level collaborative barriers encompass the absence of suitable information systems supporting collaborative activities, restrictive security measures and licensing constraints causing difficulties in implementing commercial tools and resources, and challenges in adapting solutions to dynamic environments [33]. Employees interviewed at BAE Systems further support the above claim that there is a lack of tools supporting the collaborative process [40]. Managing collaboration and communication involves handling information originating from various experts and specialized fields across the organization [5], [6], [19]. Different departments may require information in different forms, and challenges also arise in the conversion of information or data from one form to another [6]. This can also be linked to the lack of collaborative and interoperable tools employed within and across organizations [40], [47].

2.3. Communication

The literature frequently associates collaboration with communication [10], [42], [48], [49], [50], [51], [52], emphasizing their interdependence. Büyüközkan et al.'s [53] literature overview on collaborative product development recognizes communication as a fundamental success factor for collaboration.

A common theoretical description of communication is the exchange of data, information and knowledge [9], [54]. Effective communication is a critical component of collaborative design [9], [55] and product development [56] and influences team dynamics [7], information seeking [49], and task performance [56]. There have been a number of reported project set backs or failures associated with communication problems, specifically in collaborative development programs [13], [57], [58], [59], [60]. The root cause of communication breakdowns can be difficult to identify, given their dependence on multiple factors and connectivity to process issues [9], [13]. Due to the unique nature of an organization's processes, there is no definitive solution to managing communications across the various platforms. Therefore, acknowledging the factors that influence communication and understanding the current state process of communication can be beneficial to the organization's productivity and performance [13].

2.3.1. Communication tools

The efficiency of communication can be impacted by the method in which the sender chooses to convey a message [50], [58], [61], [62], [63]. Communication methods include face-to-face interactions, email correspondence and telephone conversations. Over the last few decades, progress in information technology has paved the way for the increased utilization of computerized communication tools [63]. Hauser Jr. and Byrd [63] suggest that the implementation of computer-mediated communication systems can affect interdepartmental networks and shift workflows across organizations.

Studies have shown that computer-mediated communication is the most frequently used channel for employee communication [64], even for teams that are physically close or co-located [9]. Communication can also be mediated through systems such as enterprise-resource planning (ERP) [65], [66] software packages designed for integrating and managing business processes within an organization [66], [67]. An ERP system provides the ability to share, communicate and retrieve information across all collaborative departments within a single database [68]. Reporting issues, activities, and information, including work hand-offs, can all be communicated through the system, in turn decreasing the need for employees to communicate face-to-face [66].

Given the asynchronous nature and physical separation inherent in geographically dispersed teams and virtual or remote work environments, their primary reliance is on computer-mediated communication utilizing communication platforms, virtual calls, email, and digitized documents [58], [69]. Challenges arise in overcoming communication barriers such as a lower frequency of communication among participants [69], delays in response time [70], the potential for misinterpretation of messages [71], and the lack of immediate feedback [56].

Co-location has proven effective in promoting face-to-face contact, informal communication [52] and knowledge sharing [72]. Proximity allows for frequent communication, increasing the likelihood of casual, spontaneous exchanges, which facilitates successful working relationships and collaborations [52]. However, the frequency of face-to-face interactions typically diminishes as physical distance increases [56], [73]. Conversely, email usage tends to rise in such circumstances [56], [73]. Van Den Bulte and Moenaert [74] contend that communication is not necessarily influenced by distance. Their findings demonstrate that co-location improves oral communication within rather than across departments.

The technical capabilities of communication tools can influence the quality of communication, and differences between information technologies can cause communication barriers among interdependent parties [56]. This includes differences among the availability and accessibility of the information or resources within the system, different familiarity or technical competency levels, and incompatible systems [56]. A case study conducted by Morton et al. [8] established that the lack of 'high quality' communication channels led to poor inter-organizational relationships. While the study fails to specify what instance(s) of the communication channel was lacking, understanding both the capabilities and limitations of the communication tools, along with their implementation and use in the organizations involved, enables the identification of potential barriers. Furthermore, mitigating the differences among communication technologies would "facilitate electronic information transfer between interdependent team members" [56].

2.4. Understanding workplace processes

In communication-centered studies, researchers have concluded that having an understanding of workplace processes; the tasks of others; and their interconnectivity can positively influence communication and collaborative efforts [8], [9], [10], [13], [75], [76], [77]. Morton et al. [8] emphasize the need to understand the impact of relationships at the boundaries of their internal and external activities as a means of improving communication flows. The benefits associated with understanding workplace processes align with those determined by Eckert et al. [9] in their discussion of auditing and understanding communication processes. These include contributions to contextual awareness, process transparency, task connectivity, potential discoveries of unknown sources of information, and eventually improved productivity [9].

For information technology (IT) system designs, Yasuoka emphasizes the importance of the designer's/developer's understanding of the collaborative environment and "its relation to activities around IT systems" [43]. In the context of virtual collaborative environments, the differences in the understanding of workplace processes among team members can influence the success of collaboration outcomes [78], [79].

A genuine understanding of workplace processes is essential for organizational progress. As mentioned by Perry et al. [11], Verner [12], Laguna and Marklund [80] and Jacka and Keller [81], the first step towards identifying areas for improvement and structuring future-state processes is a comprehensive understanding of the current-state processes. Without an accurate understanding of current processes, there is a risk of implementing suboptimal solutions or addressing the wrong problem [12].

Although standard organizational processes and procedures are documented internally, the reality of the actions taken by individuals to complete their tasks may vary from these written procedures. Recognizing behavioral and systemic variances from standardized processes can be challenging and often lead to the normalization of such variances [36]. Individuals may deviate from documented procedures for various reasons, which can result in both positive and negative outcomes [82]. Rather than attributing such deviations solely to individual error, evaluating *why* an individual felt the need to diverge from established processes may reveal areas for process improvement. According to Ludwig [36], the behaviors of one actor can influence the behavior and outcomes of other agents within the system, highlighting the need to understand and map the behavioral system.

2.5. Process mapping

2.5.1. Introduction to process mapping

Process mapping is used to help understand how work is accomplished by providing a graphical representation of a process [83], [84], [85]. The utility of process mapping is widely recognized by leading researchers such as Damelio [83], Fricke et al. [84], Klotz et al. [85], Rummler and Brache [34], [86], and Sharp and McDermott [87]. Current-state process maps can be developed to provide process transparency, enabling stakeholders to collectively visualize, understand, communicate, and coordinate aspects of work [83], [84], [85]. Damelio [83] emphasizes that mapping a process strengthens each member's understanding of the work. By breaking down complex processes into visual representations, the resultant map can be used to identify improvement opportunities, gap analysis, and the structuring of IT system deployment or software solutions [83], [84], [85]. Findings during the evaluation of current state process maps can also be used to map future-state or ideal-state processes [83], [84], [85], [87].

2.5.2. Varying process perspectives

While there is agreement on the benefits of process mapping; the perspectives, terminologies and techniques adopted by researchers differ. Damelio views process maps as a model of *work* which is viewed as a process [83]. Despite the numerous properties and characteristics inherent in work, the maps and symbols used to model work emphasize "a limited set of boundaries, components, features and properties of work" [83, p. 35]. Damelio provides examples of important elements which are not necessarily included in a process map, such as the resources needed to execute the work and the amount of work a symbol represents [83]. This underscores the understanding that no single map shows all things, nor does a perfect map exist [83].

Curtis et al. [88] believe that a representation of a process can take on one or more perspectives. The four most common are:

- **Functional** perspectives represent what process elements (or activities) are being performed, and their relevant flows of informational entities such as data, artifacts, and products.
- **Behavioural** perspectives represent when and how process elements (or activities) are executed, including feedback loops and decision-making.
- **Organizational** perspectives represent where, and by whom, process elements (or activities) are executed, along with communication mechanisms and the locations used for storing entities.
- **Informational** perspectives represent produced or manipulated informational entities (including data, artifacts, and products) in a process and the relationships among them.

Each of these different yet interrelated perspectives exist in processes, and the authors hypothesize that if a process model were to combine these representations, an "integrated, consistent, and complete model of the process analyzed" [88] would be produced.

Giaglis [89] further explores these perspectives, assessing their alignment with different business process and information systems modeling (ISM) techniques. His evaluation demonstrates that no technique readily captures all modeling perspectives or is at least limited in its ability to do so. Considering modeling goals and perspectives can ensure that the selected technique aligns effectively with the intended purpose of modeling for a specific project. Curtis et al. [88] and Giaglis [89] emphasize the importance of comprehending the constructs and concepts within various modeling techniques, highlighting that their suitability and usability depend on their intended application. Additionally, models tailored to specific organizational views exhibit limited usability across projects with differing natures and focuses [88], [89]. Therefore, it is necessary to explore and understand different process mapping techniques and their intended application.

Rummler and Brache perceive an organization as a system-of-systems [34], [86]. Their framework, called the Three Levels of Performance, breaks down an organization into the following three levels, with the associated map type to be used.

- **Organizational Level** – views the construction of the organization's major functions, along with its relationships with customers, suppliers, and other stakeholders using a Relationship Map.
- **Process Level** – encompasses the Organizational Level, along with cross-functional processes that make up the workflow across the organization using a Cross-Functional Process Map.

- **Job/Performer Level** – encompasses the Organizational and Process Level, along with the individuals involved in the process, detailing the performers, inputs, outputs, consequences, and feedback, using a Role/Responsibility Matrix.

According to Rummler and Brache, the Process Level offers the "area of greatest opportunity for most organizations… because it is tends to be the least understood" [34, p. 63]. However, each Level of Performance provides a different view of the organization, offering unique insights that cater to the diverse needs of stakeholders [34], [86].

2.5.3. Process mapping techniques

The choice of mapping technique is influenced by the intended purpose of modeling and the type of process under consideration [84], [89], [90]. Damelio [83] and Sharp and Dermot [87] present process mapping techniques that differ in their approach. Both approaches offer insights into visualization techniques, focusing on different aspects of processes. Their methods provide distinct ways to represent a process, catering to various organizational and user perspective needs.

Damelio [83] builds upon the Three Levels of Performance framework established by Rummler and Brache [34], [86]. He presents his methodology for constructing and utilizing Relationship Maps at the Organizational Level, and Cross-Functional Process Maps, also named "Swimlane Diagrams", at the Process Level. In contrast to Rummler and Brache's focus on the Role/Responsibility Matrix at the Job/Performer Level, Damelio introduces flowcharts to capture the sequence of work activities for a single output at this level [83].

Similar to the definition provided by Rummler and Brache [34], [86]; Damelio [83] views the Relationship Map as a tool to identify the parts of an organization and the relationships between them. By mapping the sequence of inputs and outputs, these maps show how resources are connected and transformed across the organization.

Damelio [83] describes the Cross-Functional Process Map, also known as the Swimlane Diagram, as a tool to illustrate a workflow that encompasses the entire work process and the various functions involved. He defines workflow as series of interrelated work activities and resources that transform inputs into outputs [83, p. 73]. In this process map, activities performed by different organizational units are depicted within their respective horizontal bands, called "swimlanes" [83].

At the Job/Performer Level, Damelio [83] introduces flowcharts to detail the sequence of individual work activities involved in producing a specific output. Unlike broader maps, flowcharts focus on the intricacies of specific tasks, categorizing them as either value-creating or non-value-creating. He introduces a set of predefined symbols, such as the square or rectangle to represent individual activities, and diamonds to indicate decision points.

Damelio [83] and Rummler and Brache [34], [86], demonstrate how the same work can be represented by the Three Levels of Performance. They emphasize that the effectiveness or utility of the chosen mapping technique may differ for various members within an organization. In other words, even though the maps may represent the same work, their practical value and applicability can vary based on the roles and perspectives of different stakeholders.

Sharp and McDermott [87] describe Swimlane Diagrams as one of the many modeling techniques used to graphically represent a business process. Although terminology may vary – terms like Swimlane Diagram, Process Map, and Process Workflow Model are often used interchangeably – this type of diagram is useful for highlighting not only the "what" of the process, but also the "who, how, and when" [87, p. 202]. The authors provide detailed rules and guidelines for constructing Swimlane Diagrams, specifying the use of only two symbols: a rounded rectangle representing each step or activity and arrows representing the flow of work. Another constraint in their methodology pertains to the placement of steps, where the sequence must proceed from left to right, indicating the dependency among the steps over time. Additionally, their approach mandates that each actor has their own swimlane, illustrating the work contributed by every actor. However, other mapping techniques do not show *every* actor, but focus on the function or department responsible for the work [83], [87].

Colligan et al. [91] point out that careful consideration should be taken when choosing the type of process map, and they demonstrate that the layout of a process map can influence the perception of the state of quality and safety within the process. Furthermore, they recommend considering the possibility of using more than one type of map to highlight the different aspects of a process.

2.6. Case Studies

The case study is a research methodology developed within the social sciences, but applicable to a variety of fields such as planning, business, management, and engineering [27], [92], [93], [94], [95], [96], [97], [98], [99]. Recognized for their ability to capture the complexity of present scenarios [93], [100], case studies are a means of investigating a phenomenon through detailed contextual analysis within its real-world context without any control over behaviours [100]. Yin says that "you would want to do a case study because you want to understand a real-world case and assume that such an understanding is likely to involve important contextual conditions pertinent to your case" [100, pp. 13–14]. Case studies offer a holistic, in-depth understanding of the social and behavioural conditions, contrasting with quantitative methods [93], [100]. Typically, a case study deals with many variables of interest and requires multiple sources of evidence [100].

Triangulation refers to the use of multiple sources of data, methods, theories, or investigators to ensure the validity and diminish research biases of the findings in case study research [92], [101]. Yin emphasizes the importance of data triangulation to ensure accurate portrayal of events [100]. This could be achieved by using a variety of data sources [92], [100], such as observation, interviews, documents, participation, and artifacts, and converging the findings to create a 'single reality' [100].

Variations in applying case study methodology include conducting either single or multiple case studies or integrating the case study with other research methods like surveys or interviews.

According to Yin [100], a single case study is chosen when it is deemed critical, unusual, common, revelatory, or extreme. He perceives multiple-case studies as a means to gather more evidence to enhance and support the results by replicating findings. Although some may consider multiple-case studies to yield stronger conclusions than single-case designs [93], [102], the specific rationale for single-case designs is not typically met by researching multiple cases [100].

Conclusions drawn from case study findings can be generalized and applied to similar situations by making appropriate comparisons [92]. Although the generalization of single case studies has been questioned [93], analytical evidence demonstrates its feasibility in contrast to statistical methods [100]. Generalizations in a single case can be made from the principles established by the case [103]. However, generalizations should be made by those interested in applying the case study's findings to their own situations, as the researcher does not know who the receivers are [103].

Case studies are widely utilized to investigate complex phenomena and provide insights into real-world contexts. In the manufacturing industry, Chindondondo et al. [96] demonstrated the relationship between manufacturing strategy and operational performance through the use of multiple case studies. Rybicka et al. [98] utilized case studies to understand and analyze the scale of scrap material produced in four individual composite manufacturing processes to assess its potential value in terms of reuse and recycling capabilities. By mapping each manufacturing process and capturing the flow of material, they were able to characterize the type and amount of waste produced at each point where material scrap was created [98]. A case study conducted by Kagioglou et al. in the construction industry demonstrated the application of a production process mapping technique to identify dependencies of project information specific to that particular case [99]. The use of a case study helped acknowledge real-life challenges faced in the project environment [99]. Case study methodology has been applied in the aerospace sector. Cartile [27] explored process mapping to expose product lifecycle management (PLM) driven communication and process-control gaps and overlaps in the aircraft modification industry through a case study. Amrani and Ducq [97] analyzed the implementation of lean practices in the aerospace sector, highlighting the role of case study research as the investigation method. These examples underscore the versatility of the methodology across disciplines and its efficacy in elucidating complex processes and phenomena.

A single case study was chosen for the project that is the subject of this thesis. The study maps a specific aerospace process to better understand the various contributing factors. The adoption of the case study approach allows for an in-depth exploration of the cross-functional nature of the process. By focusing on a specific case, the research seeks to extract principles that could be applicable to similar complex aerospace processes. The study provides a holistic understanding of the process, offering insights that are valuable not only for the selected case but also for broader applications within the industry.

Chapter 3. Research Objective

The study that is the subject of this thesis employs a process mapping approach to investigate a multidisciplinary aircraft manufacturing process at a Canadian maintenance, repair & overhaul (MRO) organization. The process under investigation involves interactions between Production and Engineering personnel while addressing product non-conformances during aircraft maintenance operations.

The intent of the study is to explore the usefulness of the process mapping technique as a means of capturing and understanding the factors that contribute to this complex cross-functional process. Several different levels of mapping detail are explored as a means of addressing the following questions:

1. How can inter- and intra- departmental collaboration be captured in a process map?
2. What artifacts are used to manage the knowledge associated with a process?
3. How can the information flow that is part of an interdepartmental collaboration be shown on a process map?
4. How can the process map be used to clarify the roles and expertise required?
5. How can communication methods and tools be identified/represented in a process map?
6. Can process maps be used to identify gaps and overlaps at the various levels of detail of a multidisciplinary process?
7. Does including artifacts, roles, communication tools, and hands-on time in a process map reveal information that would not typically be available from a task-focused process map?
8. What levels of process mapping detail are most useful for specific end users or purposes?

Chapter 4. Research Methodology

In this study, a multidisciplinary process is investigated by means of a case study performed on-site at a medium-sized aircraft MRO company in Canada. The process involves Liaison Engineering subject matter experts (SMEs) dispositioning non-conformances identified by Production SMEs during maintenance and overhaul activities. Non-conformances occur when there are deviations or discrepancies from established standards, specifications, or requirements.

Mapping the current-state process at different levels of detail involved several research activities as depicted in Figure 1. The activities include an initial familiarization with the process and the subsequent iterative steps of gathering data; initiating and updating process maps; reviewing intermediate results; and validating both intermediate and final process maps. Each of these steps is elaborated upon in this chapter.

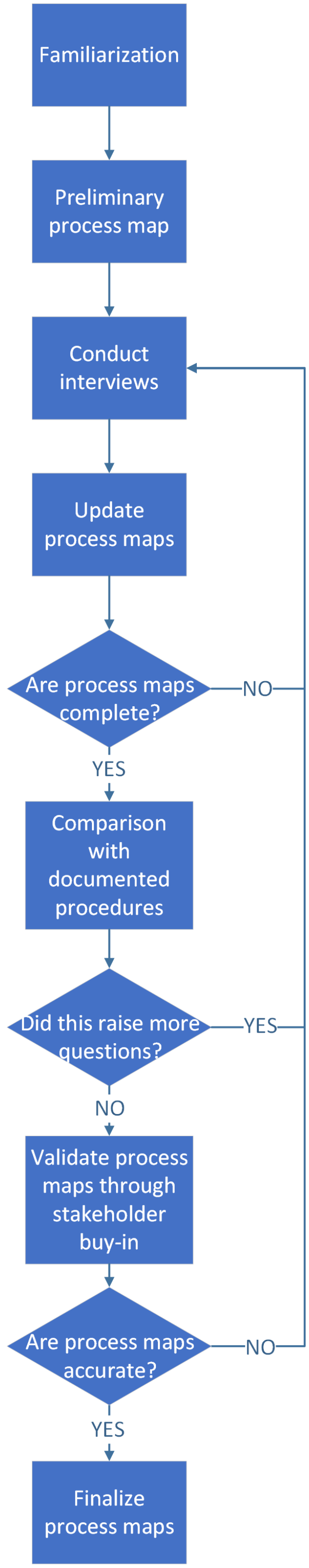


Figure 1: Research methodology for case study.

4.1. Process familiarization

Familiarization with the organizational structure, ongoing programs, the departments involved, and the procedures was accomplished on-site at the MRO facility. The researcher worked for four months at the organization as a member of the Liaison Engineering team in the context of an industrial-academic partnership.

The familiarization process involved observing individuals in the Liaison Engineering department responsible for tasks including receiving notifications of non-conformities, also called Engineering Support Requests (ESRs); managing workflows; and providing dispositions to the Production team. The identification of the actors and their roles and responsibilities was used to initiate the data collection process.

The information collected throughout the familiarization phase was used to create an initial high-level process map that reflected the researcher's familiarization experience and served as a means of identifying candidates for interviews and documents for information retrieval.

4.2. Data collection

Data used for the process maps created in this study was collected from two primary sources: interviews and company documents.

4.2.1. Interviews

One-on-one semi-structured interviews were conducted in-person with subject matter experts (SMEs) from the Production and Engineering departments. The purpose was to capture each actor's roles and responsibilities in the current-state process of raising a non-conformance and dispositioning a solution. Many interviews were conducted as an iterative data collection method for the building of the process maps. An appointed notetaker assisted throughout all interviews. The data collected by both the interviewer and the notetaker were compared to ensure accuracy.

The first round of interviews focused on establishing a shared understanding of the process between the researcher and process actors. This involved clarifying the individual roles and responsibilities and any information gaps in the researcher's first-hand observation of the process. It was noted that some actors played multiple roles in the process. A total of eleven first-round interviews were conducted, six of which were with members of the Liaison Engineering department and five within the Production department. This ensured that every identified role involved in the raising and resolving non-conformance process was accounted for. Table 1 lists the different actors interviewed in the respective departments.

Table 1: Distribution of interviewees across the actors in the Liaison Engineering and Production department.

Department	Actors	Quantity of interviewees
Liaison Engineering Department	Liaison Engineering Supervisor	1
	Liaison Engineering Lead	1
	Liaison Engineer	2
	Liaison Engineering Quality Checker	1
	Delegate (Approved Data Airworthiness Engineer)	1
Production Department	Operations Manager	1
	Senior Crew Lead	1
	Crew Lead	1
	Technicians	2

Following the researcher's observations during the familiarization process, a preliminary set of questions was developed for each role identified. These questions served as a guide during the interviews, covering common inquiries for all participants and tailored queries specific to each role and perceived workflow. The interview structure gave the interviewer the ability to modify the questions and ask follow-up questions relevant to the interviewees' responses [104], allowing the them to capture information from the interviewees' perspective and ensuring accurate information. Common opening questions included inquiries about the interviewee's role, job responsibilities, and involvement in the process of raising or dispositioning non-conformities. The set of first-round interview questions for each role can be found in Appendix A. The data collected after each interview was analyzed and used to update the process maps.

Second-round interviews were held to address any gaps identified in the updated process maps and to gather additional information. The roles selected for these interviews – one technician and one senior crew lead from the Production department, and two liaison engineers from the Liaison Engineering department – were chosen because they were directly associated with areas of the process where information was incomplete or unclear. The set of interview questions focused on identifying the series of steps required by each role in the process and to clarify authorized actions at each step. The set of second-round interview guided questions for each role can be found in Appendix B.

Remaining or follow-up questions after the second round of iterated process maps were resolved through informal meetings and conversations with the individuals assigned to the relevant roles.

4.2.2. Document review

The interviews identified internal documents outlining the daily tasks related to the non-conformance process in both the Engineering and Production departments. Internal documents including policies, process procedures, work instructions, task cards and forms were reviewed to supplement and validate the information contained in the process maps. Any discrepancies between the mapped process and the documented procedures were addressed with the relevant stakeholders. The objective was to accurately depict the actual operational practices, even if they deviated from documented protocols.

4.3. Process map development

The information collected as described above was used to iteratively build the process map at various levels of detail. Five process maps were created, with each map providing a greater level of detail than its predecessor.

4.3.1. Modeling tool

Microsoft Visio was selected as the modeling tool due to its availability, ease of use, customizability, and collaborative features. Visio supports a wide range of modelling techniques and notations including (Business Process Mapping Notation) BPMN, unified modeling language (UML), Icam DEFinition for Function Modeling (IDEF0) and it's own flowcharting technique [105]. Another reason for implementing Visio as the modeller is its widespread popularity, ensuring a relative ease of understanding for stakeholders.

A Visio flowchart visually represents steps in a process using standard symbols linked by arrows. It displays the steps, decisions, and outcomes of a process. These flowcharts are commonly used in business, engineering, and software development applications to effectively illustrate and communicate processes [106].

4.3.2. Process map set-up: phases and swimlanes

The process maps in this study maintain a consistent layout across all levels of detail. This approach, adapted from Rummler and Brache's [34], [86] process level of performance, facilitates the visualization of workflows across multiple functions. Rummler and Brache refer to this as a cross-functional process map, while Damelio [83] describes it as a swimlane diagram. This setup can link activities, people, information systems and other resources throughout the workflow. The resulting map format, illustrated in Figure 2, features the functions or departments on the left-hand axis, each contained within a horizontal band or "swimlane". The Production and Liaison Engineering departments are represented vertically on the left-hand axis, with the Production swimlane at the top and the Liaison Engineering swimlane at the bottom. The process is represented by five phases across the top of the maps, as follows:

Phase 1. Raising an ESR & Providing an Initial Response;

Phase 2. ESR Categorization;

Phase 3. Supplying Disposition & Production Work;

Phase 4. Engineering Authorization & Approval; and

Phase 5. ESR Closing & Archiving.

Individual activities are mapped within the appropriate department's swimlane and process phase. The intent of this configuration is to evaluate its effectiveness in answering the first research question: *How can inter- and intra- departmental collaboration be captured in a process map?*

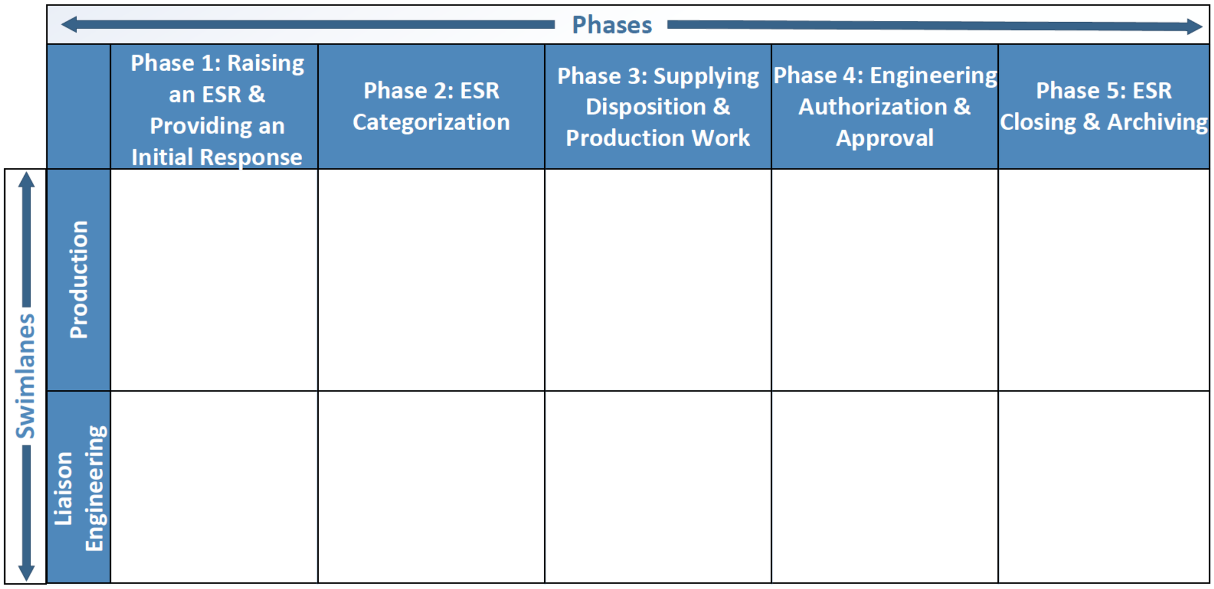


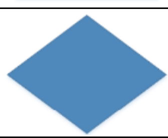
Figure 2: Process map set-up.

4.3.3. Level 1 process map

The first process map is intended to illustrate workflow at a high-level with minimum detail. The objective is to capture the principal tasks and milestones and give an overview of the overall workflow across swimlanes. Stakeholders can use this type of map to obtain an understanding of the multidisciplinary process; assess if it aligns with organizational and process goals; and to evaluate alternative organizational structures. Clarifying processes at this level can also identify collaboration within and between departments along with the associated requirements.

The symbols utilized in the Level 1 process map are illustrated in Table 2, with their respective shape names and description.

Table 2: Legend of symbols for the Level 1 process map.

Symbol	Shape Name	Symbol Description
	Start/End	Represents the start or end of the process.
	Activity	Indicates an action, task, or activity performed as part of the process.
	Decision	Represents a decision point in the process, branching based on different outcomes.

	Arrow Connector	Indicates the direction of flow between process steps, showing the workflow sequence.

A start/end symbol defines the boundaries of the work [83]. While not commonly used in cross-functional process mapping, this is a conventional symbol used in flowcharts to denote the start or conclusion of a process [83]. The activity symbol, typically in the shape of a square or rectangle, represents an action, task or activity within the process. Damelio [83] employs this symbol in both the cross-functional process map and flowcharts. A decision symbol signifies a decision point with at least two labeled output paths to reflect the different possible flows of work based on the decision. Damelio [83] introduces the decision symbol in flowcharts, whereas Rummler and Brach [34] demonstrate its use in cross-functional process maps. Arrow connectors are standard across mapping types and approaches [34], [83], [86], defining the sequential flow between process steps, task, or decisions.

4.3.4. Level 2 process map

In response to the traceability and information management demands within the aerospace sector, the second-tier process map explores the integration of information "artifacts". This type of process map is intended to illustrate workflow alongside information flow to examine if information flow has an influence on the sequence of work activities. This representation of the process can serve as a valuable tool for identifying specific information and artifact needs for individual functional groups. Additionally, stakeholders can use this type of process map as an evaluation tool to determine if information is managed efficiently.

Building on the methodology and symbols outlined in the first-level process map described in Section 4.3.3, Table 3 presents the additional symbols introduced in the Level 2 process map.

Table 3: Legend of added symbols for the Level 2 process map.

Symbol	Shape Name	Symbol Description
	Artifact	Represents an artifact, such as a document, report, or database generated or used within the process.
	Subprocess	Indicates a set of steps that form a separate process, which are detailed further in another process map.
	Dashed Connector/Association Line	Denotes a non-sequential relationship between elements, often used to link documents or additional information to a process step.

The artifact symbol, referred to as a paper output in Damelio's [83] flowcharting methodology, is introduced in the Level 2 process map to illustrate any artifact associated with an activity or step, and can denote both paper and digital artifacts. The subprocess symbol is introduced to contain a series of steps that can be considered its own process. Although not included in Damelio's [83] or Rummler and Brache's [34] methodologies, this symbol helps simplify the map by representing a subprocess with a single shape hyperlinked to a separate map. A dashed connector is sometimes used when a process step is associated to one or more artifacts.

For the process that is the subject of this case study, information exists in four distinct forms: i) digital information internal to the ERP system; ii) information in PDF format, either extracted from the ERP software for use outside the system or saved from Word document templates; iii) information existing as paper documents that have no digital representation; and iv) digital information stored externally to the ERP system. Adding a colour-code to different information formats provides a visual representation of how information is transformed throughout the process. Table 4 presents the symbols and color schemes employed for each artifact in the process map along with a brief description of the intended use.

Table 4: Legend of artifact symbols with their respective information format type and descriptions.

Artifact Symbol	Symbol Description
Digital information internal to the ERP system	Represents a digital artifact or information internal to the ERP system
PDF forms or documents	Represents a digital artifact or information found in a portable document format (PDF) form or document
Physical paper documents	Represents a physical artifact or information found in a paper document
Digital information external to the ERP system	Represents a digital artifact or information external to the ERP system

4.3.5. Level 3 process map

In many aerospace organizations, the execution of process activities involves actors distributed across departments or functional groups. Interviewing a minimum of one individual per role ensured all existing activities were accounted for. Since individuals' actions can significantly impact process outcomes [36], [82], the next level of detail added to the process map involves mapping each role to the corresponding activity to accurately reflect the process.

Expanding upon the methodology and symbols of the Level 2 process map described in Section 4.3.4, a person symbol is added to the Level 3 map. The Microsoft Visio person symbol along with the symbol description can be found in Table 5. To facilitate rapid visualization, each role is assigned a colour as described in Table 6. Visualizing the different roles involved in the process serves as a tool for recognizing responsibilities, tasks or activities requiring special authority. Not only may it be useful for evaluating if people are efficiently managing the work, but it can also be useful for identifying and investigating discrepancies between documented procedures and the modeled process. The addition of roles in the process map can be beneficial to software developers and implementors to ensure the software aligns with the process and the actors involved. For instance, a task requiring special permissions must be modeled and accounted for in the software before implementation. Furthermore, capturing the reality of the process alongside the individuals who perform the work facilitates understanding and the development of strategies to design, build, examine, operate, assess, and improve the processes and human interactions.

Table 5: Legend of added symbol for the Level 3 process map.

Symbol	**Shape Name**	**Symbol Description**
	Person	Represents an individual or role responsible for carrying out a specific task or activity within the process.

Table 6: Legend of person symbols with their respective role name and department.

Department	Symbol	Role
Production		ESR Creator
		Crew Lead
		Approved Inspector
		Technician
Liaison Engineering		Liaison Engineering Lead
		Liaison Engineer
		Checker
		Authorized Engineer
		OEM Liaison
		Delegate
External		OEM

4.3.6. Level 4 process map

It has been shown that project outcomes are closely linked to effective communication, and the effectiveness of interactions between individuals is largely determined by the chosen communication mode. Therefore, the fourth level of detail explored in this case study is the addition of the communication modes.

The communication mode is added to the process maps where there is an inter and intra-departmental hand-off. The mode of communication is represented as text within a red activity symbol, as shown in Table 7. In cases where there is a reassignment of an activity between two roles, the red activity symbol is configured with the role transferring the activity positioned at the bottom corner nearest to the input arrow of that activity. The role receiving the new activity is positioned at the opposite bottom corner of the activity symbol, as depicted in Figure 3. This addition to the process map aids the identification of points where work is reassigned or transferred. The addition of *how* individuals choose to interact in the process provides a visual representation of communication flows throughout each activity, allowing the process map user to understand the communication process by providing contextual awareness and process transparency.

Table 7: Legend of added symbol for the Level 4 process map.

Symbol	Shape Name	Symbol Description
	Activity	Represents a task or activity related to the exchange or transmission of information within the process.

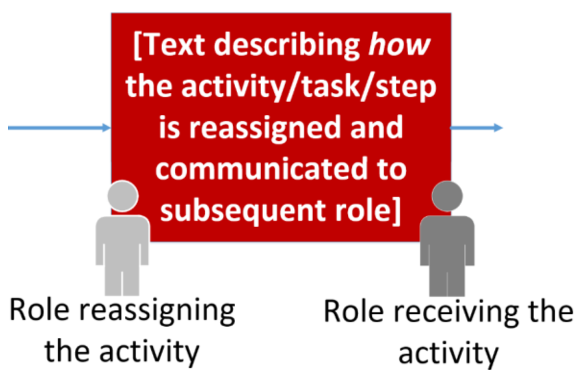


Figure 3: Symbol configuration for the reassignment of activities.

4.3.7. Level 5 process map

Productivity improvements are commonly sought after, and evaluating the time associated with a process can help identify activities that take longer than anticipated. To demonstrate the concept and potential benefit of adding time to a process map, an estimated working time has been added to the Level 4 process map using the symbol illustrated in Table 8 which is added to the top-right corner of each activity as shown in Figure 4. Most of the activities contain estimated times from the familiarization phase of the data collection process, however the times associated with some activities may vary depending on the person's availability. For example, the time to "Acknowledge email notification" can vary from one person to another, and twenty minutes was estimated as the average time to acknowledge an email throughout the whole process map. Activities such as printing and scanning are assumed to take approximately ten minutes, while automated communication done by the ERP system and the activities associated with decision symbols both assume zero minutes.

Table 8: Legend of added symbol for the Level 5 process map.

Symbol	Shape Name	Symbol Description
	Data Graphic: Circle Callout	Represents the estimated duration or time required to complete a specific activity or task.

Figure 4: Activity symbol with the annotation of an approximate working time of 20 minutes.

4.3.8. Validation

Validation sessions with key stakeholders from both the Liaison Engineering and Production departments were conducted to ensure the accuracy and comprehensiveness of the process maps. During these sessions, the process maps were presented either in printed form or as PDF documents. Each stakeholder participated in meetings where they reviewed and discussed each step in the process map. Relevant comments and feedback were integrated into the process maps. The validation process continued until each stakeholder agreed that the maps accurately depicted the reality of the process.

Chapter 5. Case Study Results and Discussion

5.1. Level 1 process map

The Level 1 process map is shown in Figure 5. Individual figures for Phases 1 through 5 can be found in Appendix D. This map captures a high-level overview of the principal tasks and associated milestones. The map is based on the information gathered in the familiarization process, interviews, and document reviews as described in Chapters 4.1 and 4.2, respectively. The principal tasks illustrated in the Level 1 map include: the identification of a problem or issue on the aircraft; the initiation of documentation raised to the Liaison Engineering department; the assignment of a liaison engineer; the categorization of the type of issue raised; the retrieval or development of a disposition; the accomplishment of the work or repair provided by Liaison Engineering; the verification that all necessary work is correct and complete; and the closing of the task and archiving of documents.

5.1.1. Swimlane requirements

The Production department is involved in Phases 1, 3, and 5 of the process map in Figure 5. They initiate the process by identifying a problem or issue on the aircraft that cannot be resolved using standard procedures. This issue is then raised as an ESR in the ERP system. Their work continues in Phase 3 with the execution of the work or repair in accordance with the engineering instructions. In the fifth and final phase of the process, the Production department is required to check and sign-off appropriate documentation to initiate the closing and archiving of the ESR.

The Liaison Engineering department is involved in all five phases of the process. Their work begins in Phase 1, when an ESR is received from the Production department and assigned to a liaison engineer. Phase 2 involves investigating whether an already approved repair or solution exists and identifying the design authority for the aircraft. In Phase 3, an appropriate disposition is identified or developed. The "yes" or "no" decision for the approval process of the disposition is excluded from this process map and the subsequent levels to further genericize the process, thereby protecting the intellectual property of the company where this case study was conducted. By illustrating it as an activity symbol, the map avoids revealing specific decision-making criteria or proprietary logic while still capturing the procedural workflow in a generalizable manner. Once the Production department completes the necessary work, the Liaison Engineering department verifies its completion and signs a checklist in Phase 4. Finally, in Phase 5, the Liaison Engineering department closes the ESR in the ERP system.

5.1.2. Cross-departmental requirements

The Level 1 process map identifies cross-departmental hand-offs. For example, the Liaison Engineering department can only begin their work after receiving the ESR from the Production department. Once the disposition has been prepared, Liaison Engineering must send it to the Production department to initiate the rework/repair. If a problem arises such that Production personnel are unable to complete the rework/repair as instructed, the ESR is sent back to the Liaison Engineering department, creating a potential iterative back-and-forth between the two departments. Once the repair/rework is completed, Production notifies Liaison Engineering to allow them to proceed with the verification and sign-off of a checklist. The Production department then gets notified by the Liaison Engineering department that they must sign-off and approve any final documentation. The final exchange involves the Production department sending back all approved documents to the Liaison Engineering department for the closure and archiving of the ESR.

5.1.3. Utility and applicability for stakeholders

This process map is useful for quickly visualizing the workflow. The principal tasks and milestones of each department are easily identifiable in their respective swimlanes, along with the associated requirements across departmental functional groups. As shown in Figure 5, seven process arrows cross into the opposing swimlanes, each representing a possible exchange of information and/or artifact between departments. Due to the potential for iterative cycles after a decision symbol, the process may require revisiting previous steps or phases, involving additional interactions between departments.

The Level 1 process map enables its users to quickly identify gaps or overlaps in the overall process workflow. Users such as executives or departmental managers may prefer such a map to analyze process alignment with organizational goals. This type of map can also assist in the effective planning and allocation of resources.

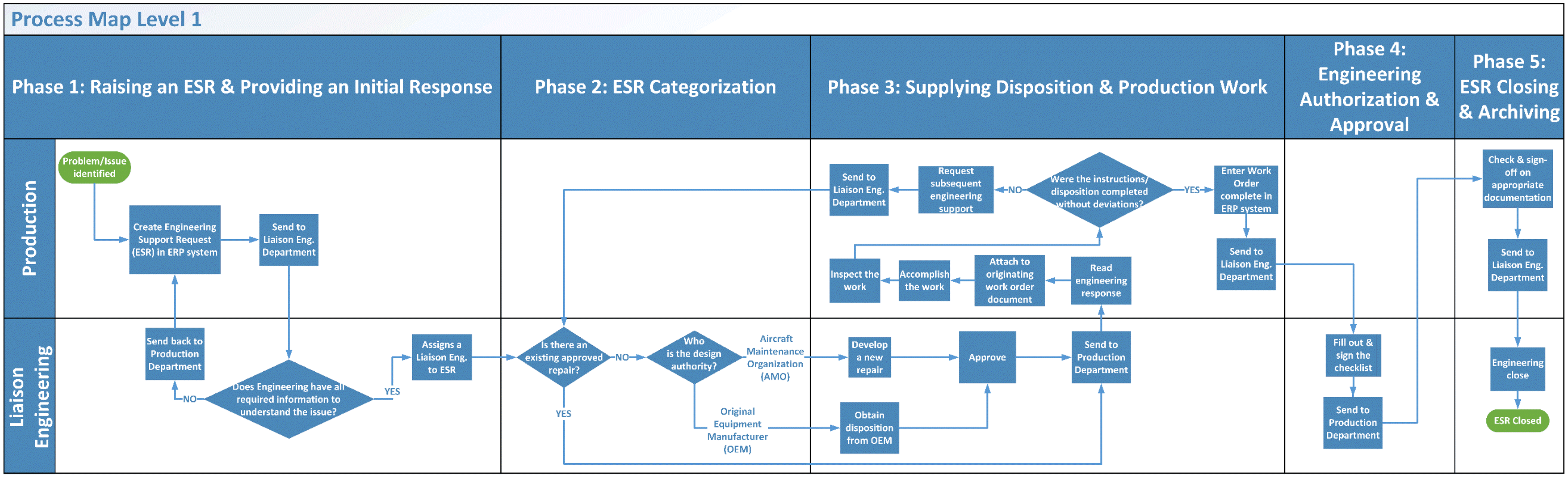


Figure 5: Level 1 process map.

5.2. Level 2 process map

The Level 2 process map is shown in Figure 6. Individual figures for Phases 1 through 5 can be found in Appendix E. This map captures the same process presented in the Level 1 process map, with the integration of an additional level of detail for information artifacts. The map is based on the information gathered in the familiarization process, interviews, and document reviews described in Chapters 4.1 and 4.2, respectively.

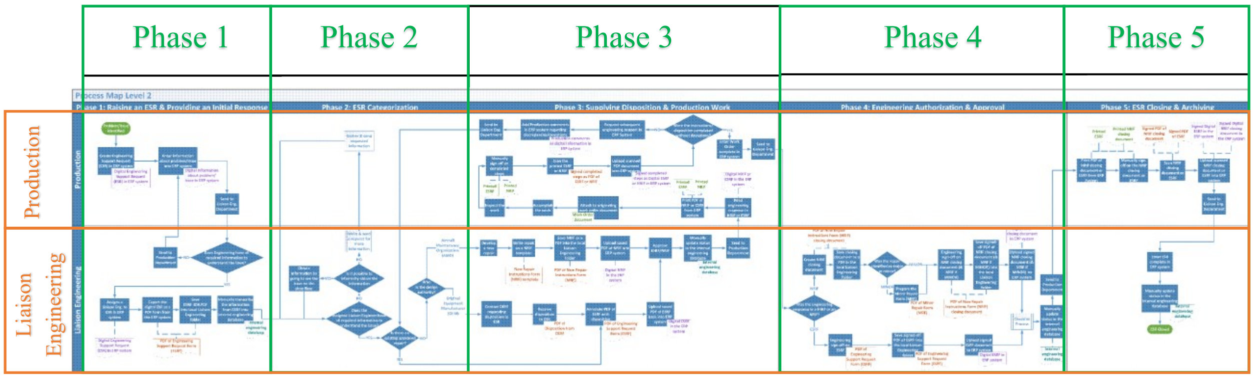


Figure 6: Level 2 process map.

The four types of information artifact identified in this process, each represented by a coloured document symbol, are linked to their respective activity box, either positioned at the corner of the activity box or connected via an association line, as shown in Figure 7. The alternative methods of representing the association between an artifact symbol and an activity box in Figure 7a and b provide equivalent visual representations, formatted specifically for this thesis. The 25 artifacts illustrated in the Level 2 process map are categorized as follows:

Digital information internal to the ERP System (purple):

1. Digital Engineering Support Request (ESR) in ERP system
2. Digital information about problem/issue in ERP system
3. Digital Engineering Support Request Form (ESRF) in the ERP system
4. Digital (New Repair Instructions Form) NRIF in the ERP system
5. Signed completed steps as Digital ESRF or NRIF in the ERP system
6. Production comments as digital information in ERP system
7. Digital NRIF closing document in the ERP system
8. Signed Digital NRIF closing document in the ERP system
9. Signed Digital ESRF in the ERP system

PDF forms or documents (orange):

1. New Repair Instructions Form (NRIF) template
2. PDF of New Repair Instructions Form (NRIF)
3. PDF of Disposition from OEM
4. PDF of Engineering Support Request Form (ESRF)
5. Signed completed steps as PDF of ESRF or NRIF

6. PDF of New Repair Instruction Form (NRIF) closing document
7. Signed PDF of NRIF closing document
8. Signed PDF of ESRF
9. PDF of Minor Repair Form (MRF)
10. Checklist template in word document
11. Checklist PDF

Physical paper documents (green):

1. Printed NRIF
2. Printed ESRF
3. Work Order document
4. Printed NRIF closing document

Digital information external to the ERP system (turquoise):

1. Internal engineering database

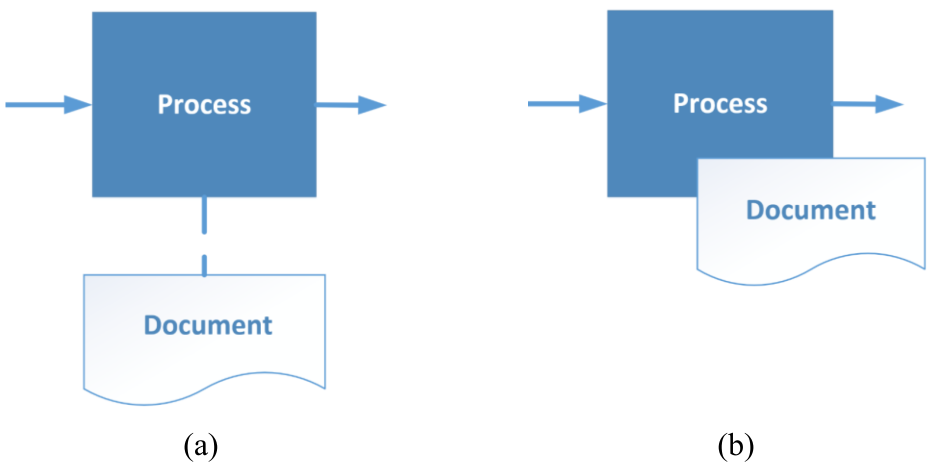


Figure 7: Illustration of the association between document and activity symbols using (a) a dashed connector and, (b) an overlapping document symbol on an activity symbol.

5.2.1. Artifact identification

An example of artifact identification is provided in Figure 8 and described in this section. A similar approach was used to identify artifacts across all five phases of the process. Figure 8 compares Phase 1 between the Level 1 and Level 2 process maps, with the Level 1 process map shown in Figure 8a and the corresponding Level 2 process map in Figure 8b.

The Level 2 process map in Figure 8b includes 4 different types of artifacts:

i) the digital Engineering Support Request (ESR) artifact itself which exists within the ERP database and is used to track the activity;

ii) the digital information that both engineering and production personnel enter in the ERP system to populate the ESR in the database;
iii) a PDF document entitled Engineering Support Request Form that is created from the ERP database and is used by engineering personnel to track the process internally and that is stored as a PDF in a local engineering folder; and
iv) digital information in non-ERP engineering database that is manually transcribed from the PDF document described above and used to track and trace engineering activity related to the ESR.

5.2.2. Addition of new activities

The addition of artifacts to the process map resulted in the identification of new activities not shown in the Level 1 map. In the example shown in Figure 8b, 4 additional activities have been added to the workflow to illustrate how the various artifacts are used to manage the information required to accomplish the task:

i) the activity of entering digital information into the ERP system in order to populate the ESR that had been created by the previous activity;
ii) the activity of creating a PDF document entitled Engineering Support Request Form (ESRF) using data from the ERP database;
iii) saving the ESRF.pdf to a local engineering folder; and
iv) manually transcribing information from the ESRF.pdf document into an engineering database used to track and trace engineering activity related to the ESR.

5.2.3. Addition of new subprocesses

When the addition of new activities to the process map became cumbersome, a series of new activities was grouped together as a subprocess. The Level 2 map is the first level where the subprocess symbol is used. Figure 9 provides an example where 2 subprocesses have been added at the Level 2 level-of-detail:

i) the “Gather and send requested information” subprocess is added to the Production swimlane; and
ii) the “Write and send a request for more information” subprocess is added to the Engineering swimlane.

Figure 10 illustrates the detailed activities and artifacts that are part of the “Gather and send requested information” subprocess circled in Figure 9. Eight new activities and three artifacts are identified as part of this subprocess. The new artifacts include:

i) a printed version of the New Repair Instructions Form (NRIF) PDF document that is used to gather and document additional information requested of Production by Engineering;
ii) a work order paper document that is used to document the production activity required to action the NRIF; and
iii) a scanned copy of the completed and signed NRIF in PDF format, uploaded to the ERP system.

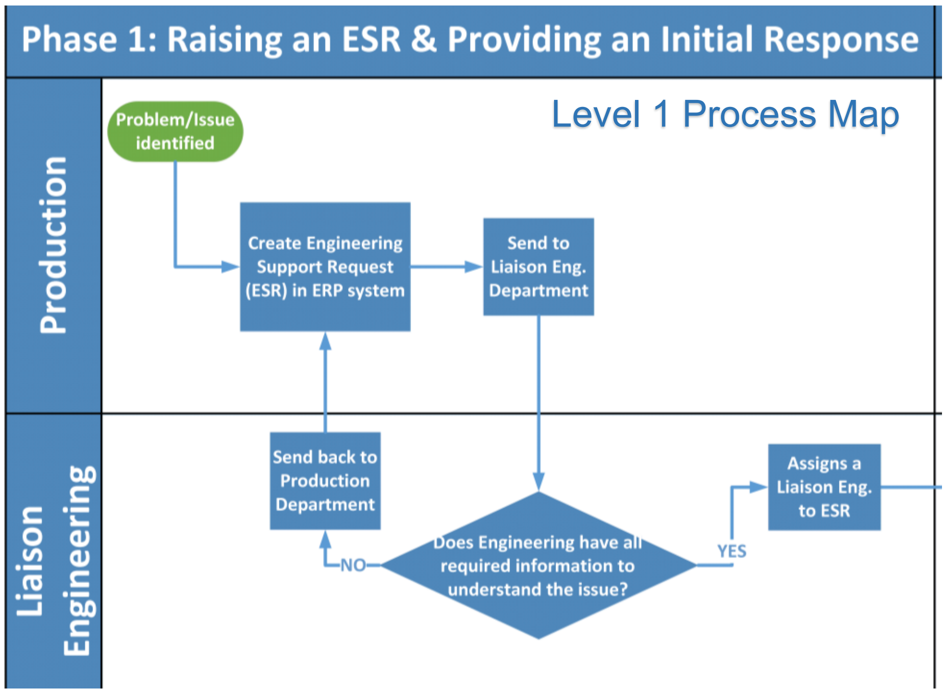
5.2.4. Utility and applicability for stakeholders

The inclusion of detailed artifacts in process maps aids in evaluating traceability and information management practices, enhancing the map's utility for stakeholders by improving process visibility and supporting informed decision-making.

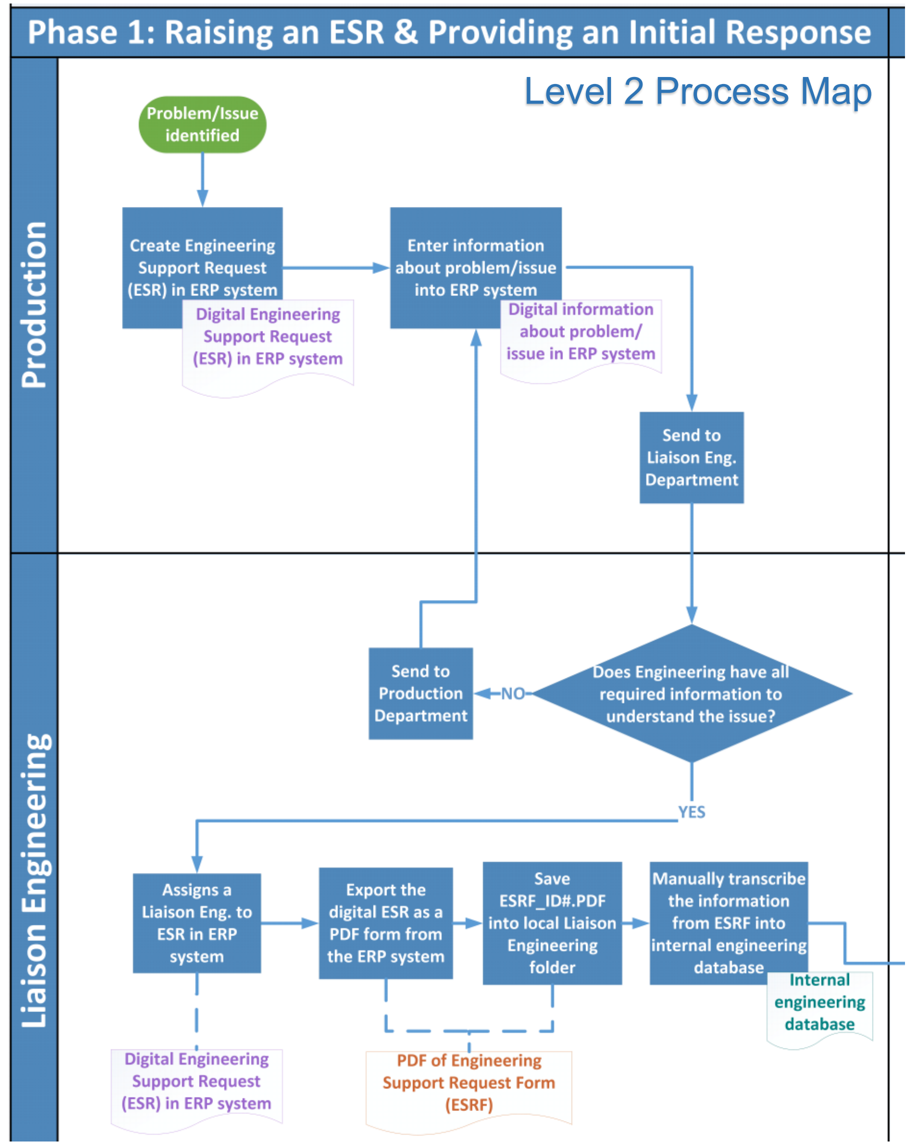
Mapping information flow with colour-coded artifact types, in addition to the process workflow, enables quick identification of patterns across collaborating departments. For example, the Production department relies primarily on physical paper documents, illustrated in the green, while the Liaison Engineering department predominantly uses digital information or artifacts found in PDF format, shown in orange. This level of visibility helps map users detect workflow dependencies and trends, offering insights into the process dynamics. Managers and operations staff can leverage this data to assess process effectiveness and resource allocation.

Tracking information artifacts throughout the process also illustrates how information is transferred and transformed, supporting traceability and ensuring accuracy and consistency across phases. For instance, the transition from a digital record in the ERP system to a printed ESRF and then to a signed PDF highlights various stages of handling and approval. This visibility aids quality assurance and regulatory compliance by ensuring decision and document traceability, which can be valuable for audits and regulatory reviews.

Identifying transformation of artifacts also provides IT and system analysts with essential data to investigate potential interoperability challenges. For example, the manual transcription of information from one database to another, as shown in Figure 8b, illustrates an instance where improved integration could streamline workflow efficiency and minimize the potential for human error. This added detail in the Level 2 process map enables comprehensive workflow analysis, facilitating process improvements and optimization.



(a)



(b)

Figure 8: Comparison of Phase 1 in process maps (a) Level 1 and (b) Level 2.

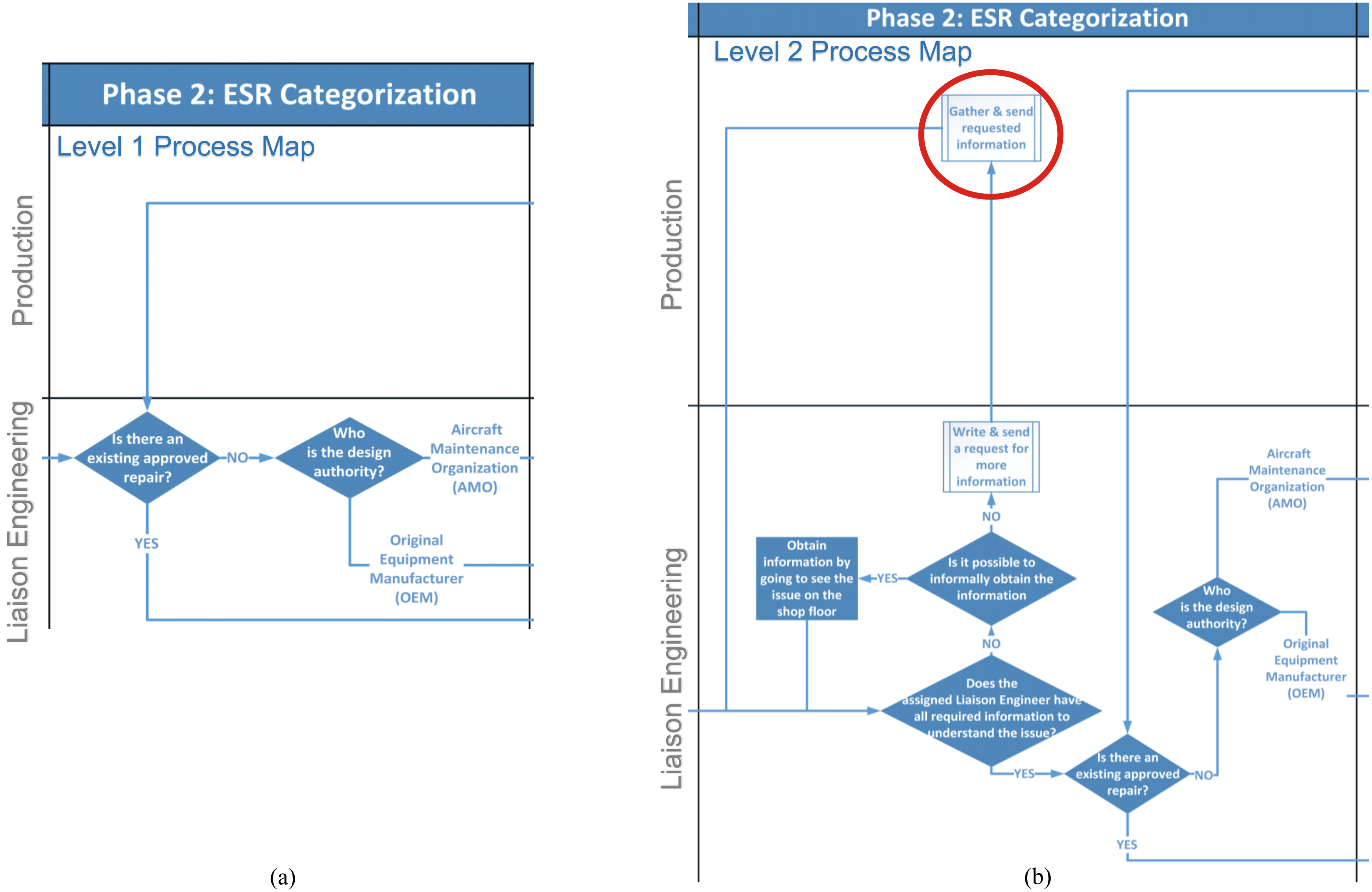


Figure 9: Comparison of Phase 2 in process maps (a) Level 1 and (b) Level 2.

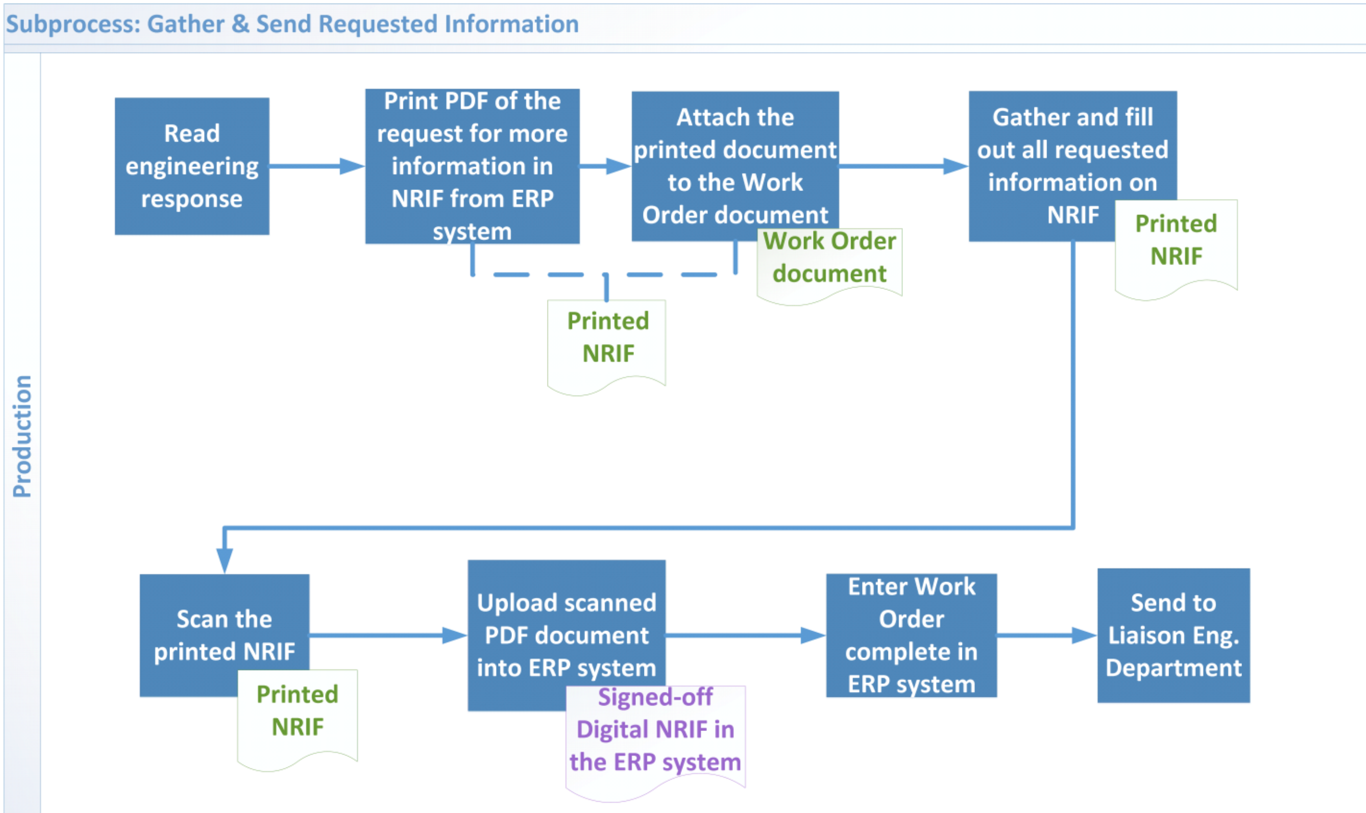


Figure 10: Level 2 subprocess.

5.3. Level 3 process map

The Level 3 process map is depicted in Figure 11, and detailed figures for Phases 1 through 5 are provided in Appendix F. This map expands upon the Level 2 process map by adding the roles responsible for each task. These roles were identified based on information gathered during the familiarization and interview process, detailed in Chapters 4.1 and 4.2.1, respectively.

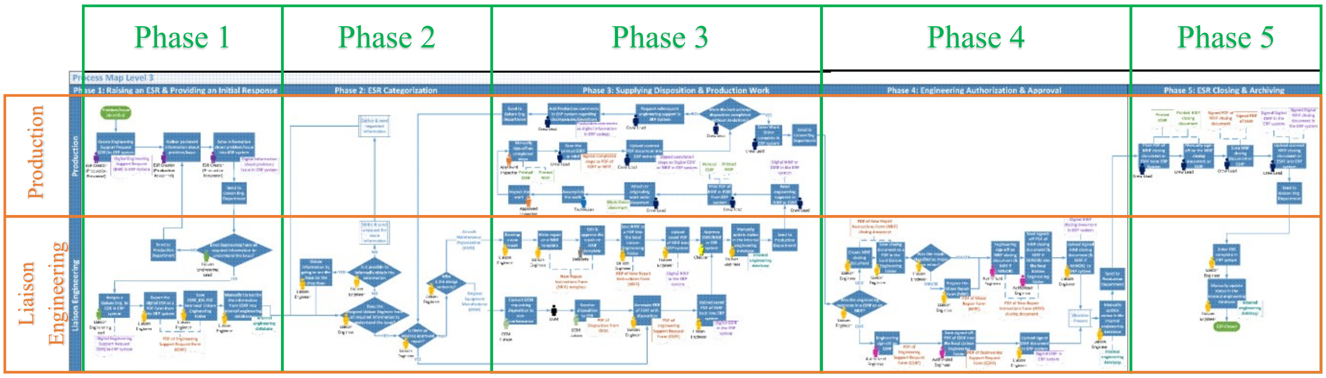


Figure 11: Level 3 process map.

The Level 3 process map adds the roles to the work and information flow of the Level 1 and Level 2 maps. Each role is represented by a person symbol, positioned overlapping their assigned activity. The 11 roles described in Table 6 are associated with the relevant tasks and artifacts in the Level 3 process map in Figure 11.

5.3.1. Role identification

Figure 12 compares the Production swimlane in Phase 3 between the Level 2 and Level 3 process maps, with Figure 12a showing the Level 2 map and Figure 12b showing the Level 3 map. The Level 3 map identifies specific roles assigned to each task, providing visibility into how responsibilities are distributed across the process. Including roles helps in visualizing task ownership and ensuring activities requiring special permissions or authorizations are correctly assigned. For example, Figure 12b shows that only an approved inspector is authorized to inspect and manually sign-off the work in Phase 3 of the Level 3 map.

Colour-coding makes it possible to distinguish the number of tasks each role is responsible for. For example, in the Liaison Engineering swimlane of Figure 13b, the most frequent role assigned is the liaison engineer, whereas in the Production swimlane of Figure 12b, the crew lead is the most common. This allows map users to assess workload distribution across roles and departments.

5.3.2. Addition of new activities

The Level 3 process map introduces new activities to more accurately reflect the task assignments of all individuals involved in the process, capturing the workflow at a higher level of granularity. For example, Figure 13a and b provide a comparison of the Liaison Engineering Phase 3 between process maps at Levels 2 and 3, respectively. The Level 3 process map requires the addition of an additional activity to permit the depiction of the role of the delegate in the process. The purple-circled task in Figure 13b illustrates the delegate's responsibility to edit and approve the repair written by the liaison engineer on the NRIF template, before it can be finalized as a saved PDF document.

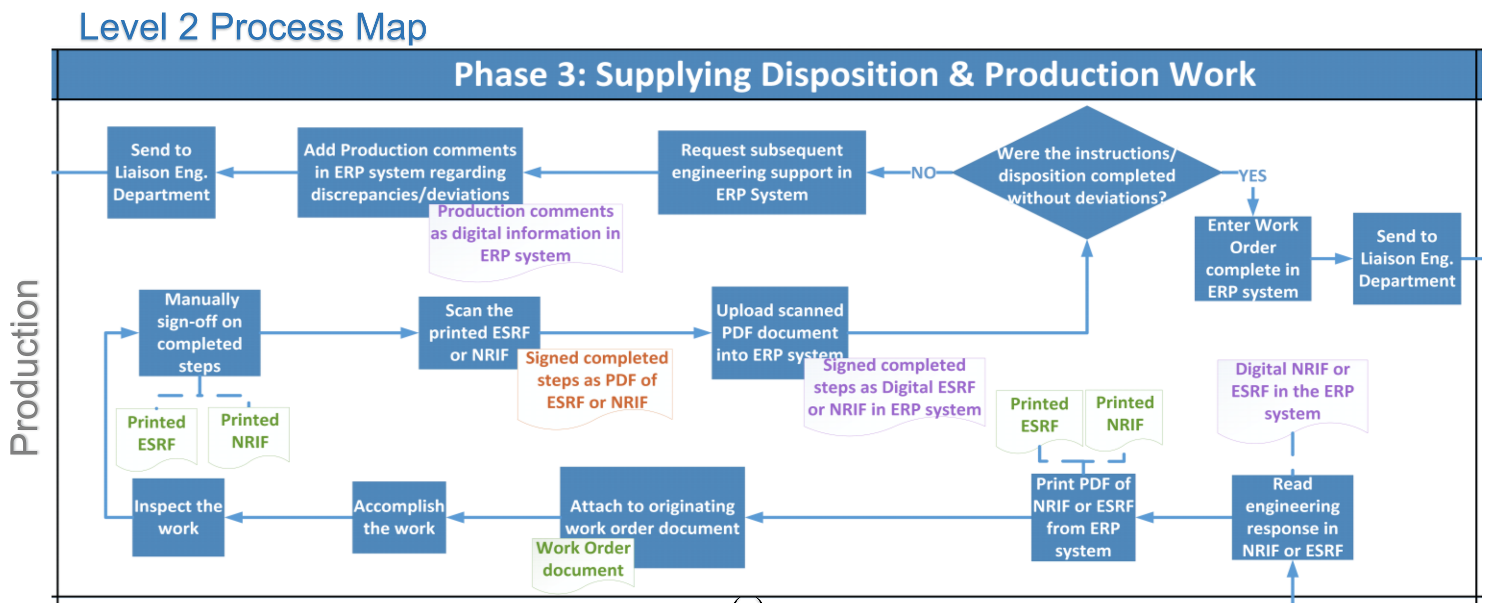
In another example, the step circled in green in Figure 13b is a person symbol linking activity boxes. This represents the transfer of work to the OEM, followed by its return to the OEM liaison in the Liaison Engineering department. This illustrates a part of the process where the ownership of the work shifts to an external stakeholder.

The inclusion of new activities in the Level 3 process map ensures that all necessary steps are documented to show how tasks are transferred between individuals and across departments. This visibility aids in gaining a better understanding of the workflow and provides clarity on where task ownership changes.

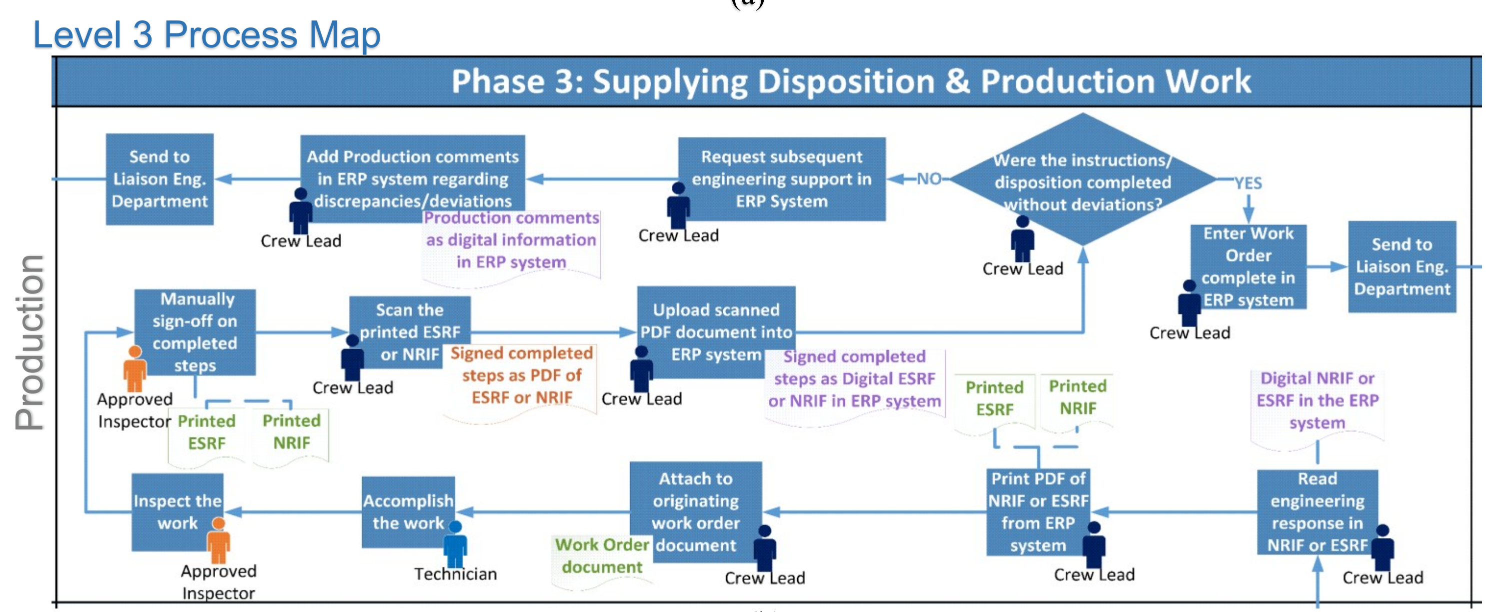
5.3.3. Utility and applicability for stakeholders

The inclusion of roles within process maps offers several benefits across different user groups. For managers and process owners, assigning roles to specific activities provides clarity on task ownership, enabling better oversight of workflow execution and resource allocation. By understanding who is responsible for each task, workloads can be managed and balanced more effectively across teams. Stakeholders who make the association between the individuals and the roles they play can also investigate any potential discrepancies between the defined standard process and the actual workflow shown in the map.

Mapping roles along the process workflow provides IT, system analysts, and software developers with insights into system integration needs and security controls. Accurately identifying actors' roles and credentials supports the development of software access controls, ensuring that only authorized personal can perform specific actions within digital systems. This helps align software with actual workflow requirements while maintaining security and data integrity. By mapping tasks to roles and their associated qualifications, developers can design systems that not only support security but also create efficient workflow structures tailored to access the needs of different actors.



(a)



(b)

Figure 12: Comparison of Phase 3 Production swimlane in process maps (a) Level 2 and (b) Level 3.

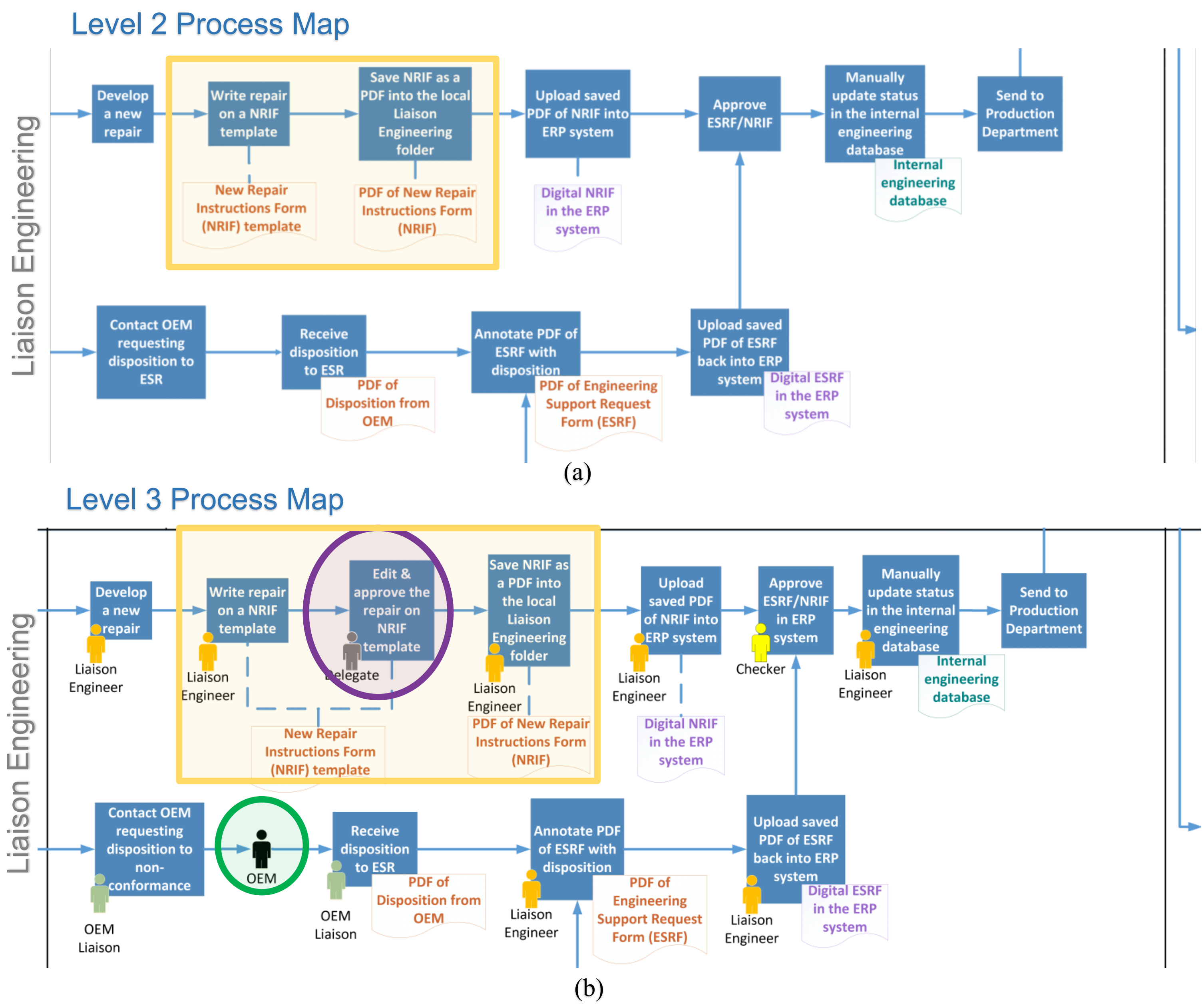


Figure 13: Comparison of Phase 3 Liaison Engineering swimlane in process maps (a) Level 2 and (b) Level 3.

5.4. Level 4 process map

The Level 4 process map is depicted in Figure 14, with detailed figures for Phase 1 through 5 available in Appendix G. This map expands upon the Level 3 process by adding the means of communication during the reassignment of activities between individual roles or departments. The means of communication are identified based on information gathered during the familiarization and interview processes detailed in Chapters 4.1 and 4.2.1.

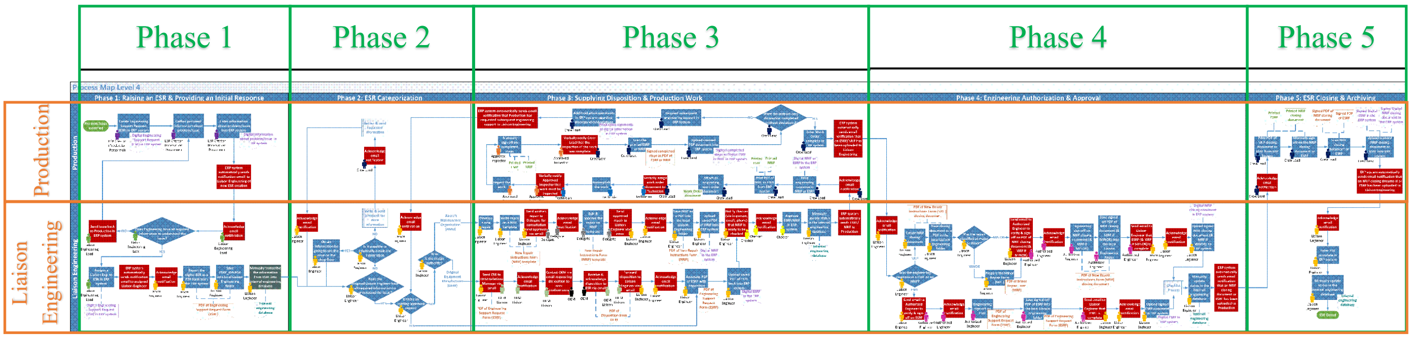
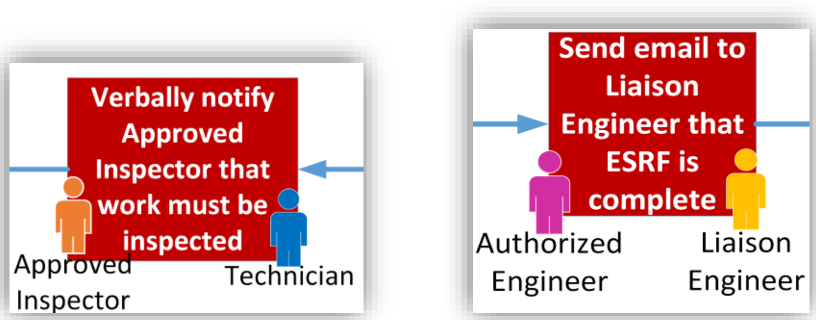


Figure 14: Level 4 process map.

The Level 4 process map illustrates the workflow, information flow, roles responsible for each activity, and communication flow. Activities involving communication, whether between different roles or departments, automated or not, are highlighted in red. Figure 15 illustrates instances of intradepartmental hand-offs, with the means of communication described as text within the red activity symbol. The communicator and receiver roles are positioned at the bottom corners of the activity symbol in alignment with the communication flow, corresponding to the direction of the workflow. There is a total of 40 distinct instances of communication identified in the main process map shown in Figure 14. The three subprocesses identified in the map contain an additional 8 communication tasks.



a) (b)

Figure 15: Intradepartmental hand-off examples between a (a) technician and approved inspector, and (b) an authorized engineer and liaison engineer.

5.4.1. Addition of new activities

The Level 4 process map includes additional activities that were not present in the Level 1, 2, and 3 maps. The Level 4 process map addresses how one individual or department becomes aware of their newly assigned task and the typical means of communication used throughout the process.

Figure 16a and b compare the Liaison Engineering swimlane in Phase 3 for both Level 3 and Level 4 process maps, respectively. In Figure 16a, the red square highlights two activities that depict the transfer of work from the liaison engineer, who documents the repair on the NRIF template, to the delegate responsible for editing and approving the repair. The Level 4 process map, shown in Figure 16b, adds two activities that provide detailed insights into the communication involved in sending and retrieving the task. All the activities highlighted in purple and green, representing sending and receiving information, respectively, were not depicted in the Level 3 map. These additional activities capture communication flow between roles, providing a more detailed view of the communication process.

5.4.2. Identification of chosen communication methods

The Level 4 process map enhances the information presented in the Level 3 map by enabling users to track communication activities between roles and departments.

For example, in Figure 16b, five activities circled in purple demonstrate the use of email for task reassignments within the Liaison Engineering department. In contrast, the purple square highlights the transfer of work between a member of the Liaison Engineering department, the OEM Liaison, and an external organization, the OEM, which is also communicated via email. Each email-based communication is followed by an acknowledgement, as email acknowledgements may not occur as immediately as verbal communications. Phase 3 of the Liaison Engineering swimlane includes a total of six email acknowledgement tasks.

The ERP system automates the final activity of Phase 3, transmitting the ESRF or NRIF to the Production department once it is approved by the checker in the ERP system. This automated task does not have a role assigned to it, consistent with the Level 3 process map's results.

Following the Liaison Engineering's Phase 3 is the Production department's Phase 3, shown in Figure 17. The Level 4 process map in Figure 17b highlights three instances of reassignments, circled in orange, all involving verbal communication. In this phase, the only instance an individual must acknowledge an email notification occurs during the interdepartmental hand-off, denoted in a green circle in Figure 17b. Acknowledgements of verbal communications are considered immediate and not depicted separately from the communication.

5.4.3. Departmental communication patterns

The detailed mapping of communication flow reveals distinct behavioural patterns within and across departments. The analysis of communication patterns among collaborating departments highlights the contrasting approaches taken by the Liaison Engineering and Production departments. As observed in Section 5.4.2, the Production department predominantly uses verbal communication, while the Liaison Engineering department relies heavily on email for both internal and external communications.

Additionally, interdepartmental communication is standardized through the ERP system, which automatically notifies receiving departments of task completions or approvals via email.

5.4.4. Utility and applicability for stakeholders

The inclusion of communication flow in a process map can prove useful for various stakeholders and purposes. Including detailed communication activities provides a more detailed view of the process, merging the functional perspectives of a process with the behavioural and organizational perspectives. This type of process map provides users with a deeper understanding of role interactions, the chosen means of communication, and the communication dynamics that shape the workflow.

IT professionals and system analysts can utilize the Level 4 process map to guide the development and optimization of automated systems. By understanding the preferred communication methods and information flow, they can align software functionalities with actual workflow needs. This alignment can enhance system usability and ensure that communications sent via internal systems, are timely and effective.

Insights into task assignments and communication activities facilitate the traceability of actions, decisions, and artifacts throughout the workflow. This traceability is enhanced by the additional information on who and how information, activities or decisions are transferred or transformed. This allows for the assessment and evaluation of proper execution. For instance, certain decisions may require written proof of communication for traceability purposes. Quality assurance teams can utilize this data to verify adherence to established protocols and identify any deviations that may require corrective action.

Management can extract findings on the inter and intradepartmental interactions and patterns to assess their effectiveness within the process. This analysis can help identify potential bottlenecks and serve as a foundation for developing strategies to improve communication and collaboration both within and across departments.

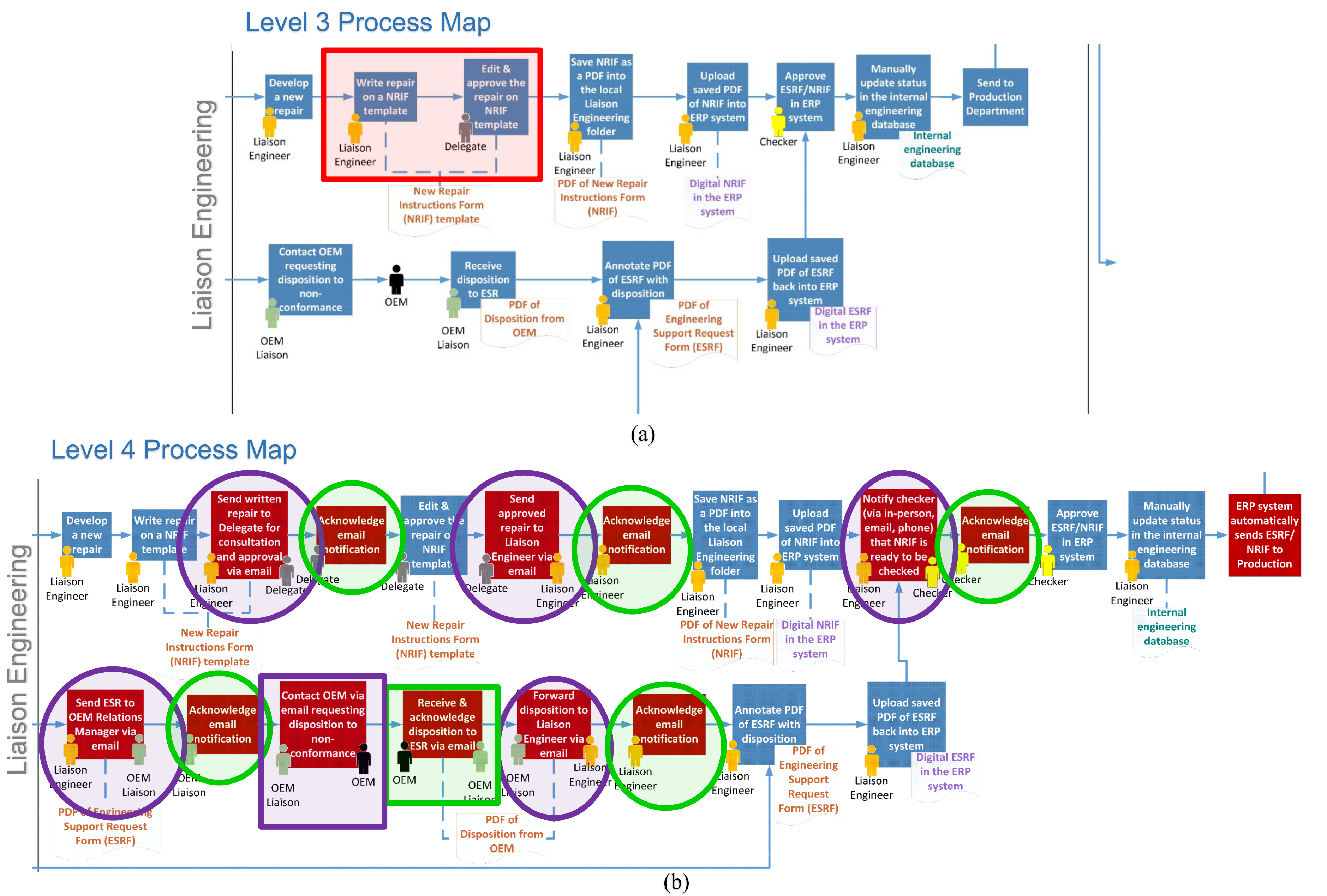


Figure 16: Comparison of Phase 3 Liaison Engineering swimlane in process maps (a) Level 3 and (b) Level 4.

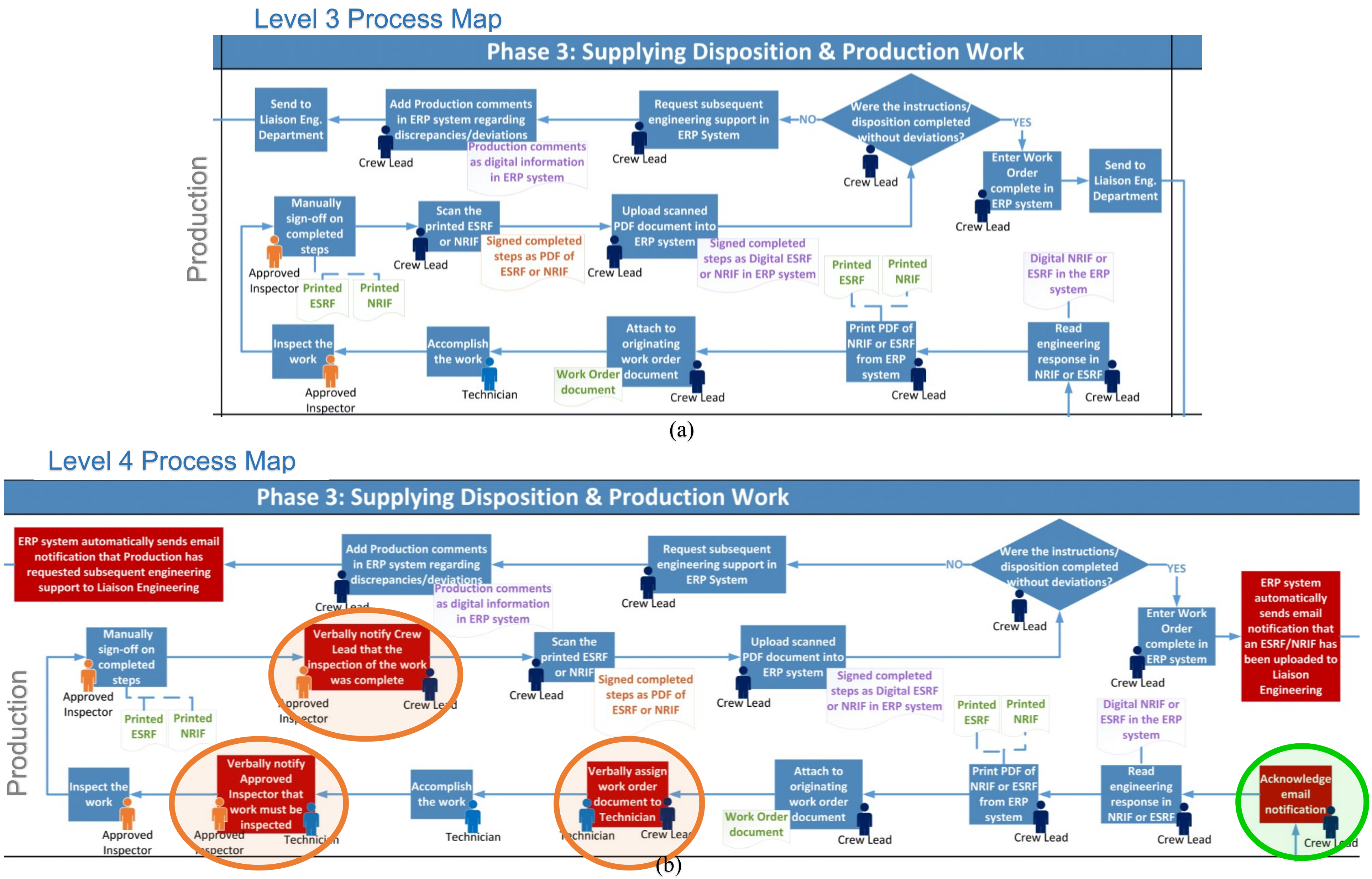


Figure 17: Comparison of Phase 3 Production swimlane in process maps (a) Level 3 and (b) Level 4.

5.5. Level 5 process map

The Level 5 process map is depicted in Figure 18, with detailed figures for Phases 1 through 5 available in Appendix H. This map expands upon the Level 4 process map by adding the approximate working time for each activity. The working time estimate is based on information gathered during the familiarization process, detailed in Chapter 4.1.

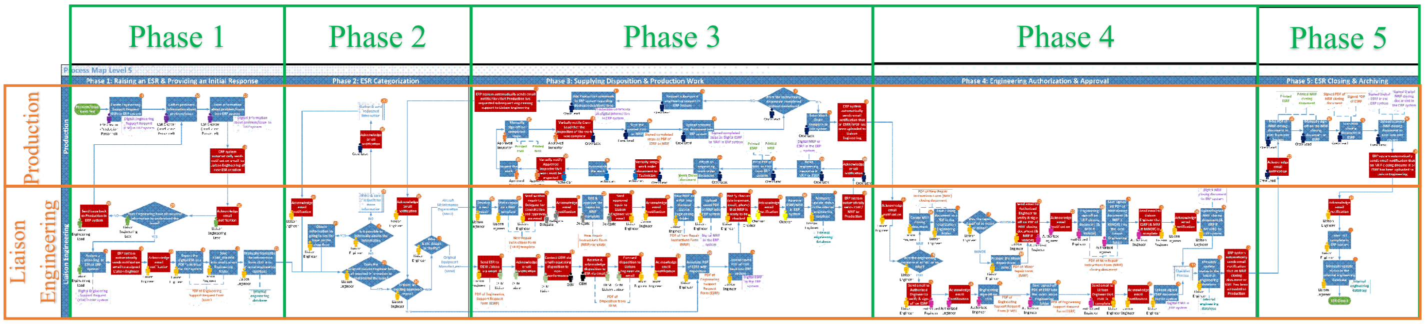


Figure 18: Level 5 process map.

The Level 5 process map illustrates the workflow, information flow, roles responsible for each activity, communication flow, and working time. All activities have an estimated time, placed in an orange circle on the top right corner of the activity symbol.

Figure 19 illustrates three different instances of working time added to existing activity symbols from the Level 4 map. Figure 19a shows a subprocess with an estimated working time of 35 minutes. This is calculated by adding up all the working time for each activity found within that subprocess, depicted in Figure 20. Figure 19b shows the added communication related activity, in the Level 4 process map, with the added working time symbol allocating 20 minutes for the completion of acknowledging an email notification. Similarly, Figure 19c demonstrates a 45-minute working time for the Approved Inspector to inspect the work. Automated tasks are assumed to take 0 minutes to complete, as shown in the red activity box, *ERP system automatically sends NRIF to Production*, in Figure 20.

(a) (b) (c)

Figure 19: Working time examples for (a) a subprocess, (b) a communication, and (c) an activity.

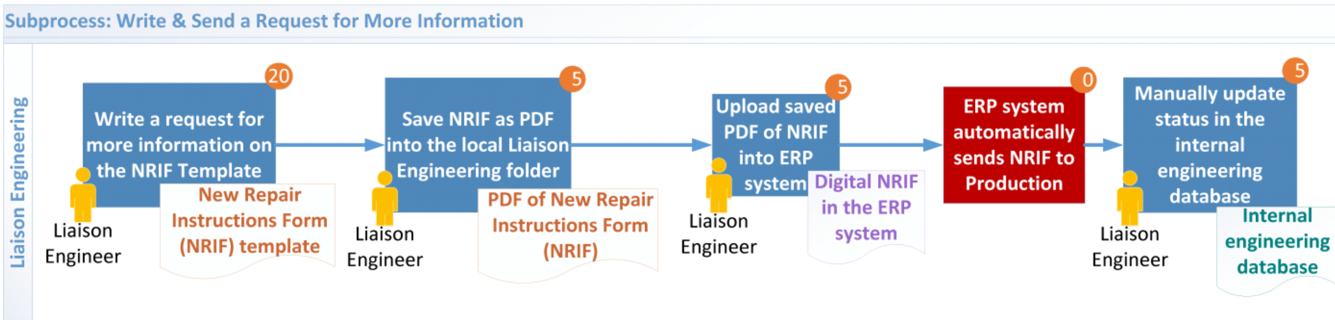


Figure 20: Level 5 subprocess.

5.5.1. Time-consuming activities

Figure 21 provides a comparison of Liaison Engineering swimlane in Phase 3 between the Level 4 and Level 5 process maps, with the Level 4 process map as Figure 21a, and corresponding Level 5 process as Figure 21b. The Level 5 process map includes additional information not available in the Level 4 map, allowing users to identify the approximate working time of each activity throughout the process. This provides a quick and clear method to identify and explore activities which take longer to execute than anticipated. Furthermore, providing information such as time can highlight potential bottlenecks in the process. For instance, Figure 21b shows the activity *Develop a new repair*, estimated to take 60 minutes. Depending on whether that time is deemed acceptable, stakeholders can further investigate whether that amount of time is required for that activity or if there are more efficient means of executing that activity.

5.5.2. Process path durations per department or phase

This approach allows for evaluating working times for different process outcomes based on decisions made throughout the process. Depending on the user's needs, it can also assess the working time of each department or phase. For instance, Figure 21b illustrating Phase 3 of the Liaison Engineering swimlane, presents three distinct paths, each dependent on decisions made in the previous phase. Each path is numbered and highlighted in Figure 21b for ease of analysis. The working time for each path is calculated by summing up the working time of each activity. The total working time for each path identified in the Liaison Engineering department's third phase of the process are as follows:

- Path #2 (highlighted in red): When there is an existing approved repair: 85 minutes
- Path #3 (highlighted in blue): When there are no existing approved repairs, and the OEM is the designated design authority: 165 minutes
- Path #4 (highlighted in orange): When there are no existing approved repairs, and the aircraft maintenance organization (AMO) is the designated design authority: 220 minutes

In this phase of the case study, the total working time varies greatly depending on the type of ESR. Path three takes approximately 94.1% longer to complete than path two, not accounting for the time it spends at the OEM, while path four takes approximately 158.8% longer than path two. The

135-minute range in the time required to complete the phase of developing a disposition highlights a potential area for further investigation into the factors contributing to these discrepancies.

Further information on the resulting total working times for individual process paths are presented in Table A. 1 in Appendix I, showcasing the sequential progression of the process across swimlanes and phases.

5.5.3. Time distribution across communication, artifacts and roles

Combining the detailed insights from previous levels of analysis with the accumulated working time assigned to the various activities opens numerous avenues for further investigation. Specifically, the total working time attributed to inter- and intra-departmental communication, the handling of artifacts, and the responsibilities assigned to each role or actor within the process can all be subjected to time-based evaluation.

Examining the time allocated to communication activities provides a perspective on how information flows between departments and within teams. By quantifying the duration spent on communication, including the initiation, transmission, and acknowledgment activities, it becomes possible to identify inefficiencies or delays that impact workflow efficiency.

Similarly, investigating the handling of artifacts throughout different process stages offers insights into the effectiveness of information management practices. This includes tracking the time spent on retrieving, updating, and utilizing artifacts essential to task completion. Understanding these workflows helps identify areas where improvements in artifact management could restructure processes and enhance productivity.

Furthermore, analyzing the time invested in individual responsibilities across the various roles involved in the process provides insight on task distribution and workload allocation. By documenting the time each role must spend on executing assigned tasks, it becomes possible to optimize role effectiveness and ensure equitable distribution of responsibilities among team members.

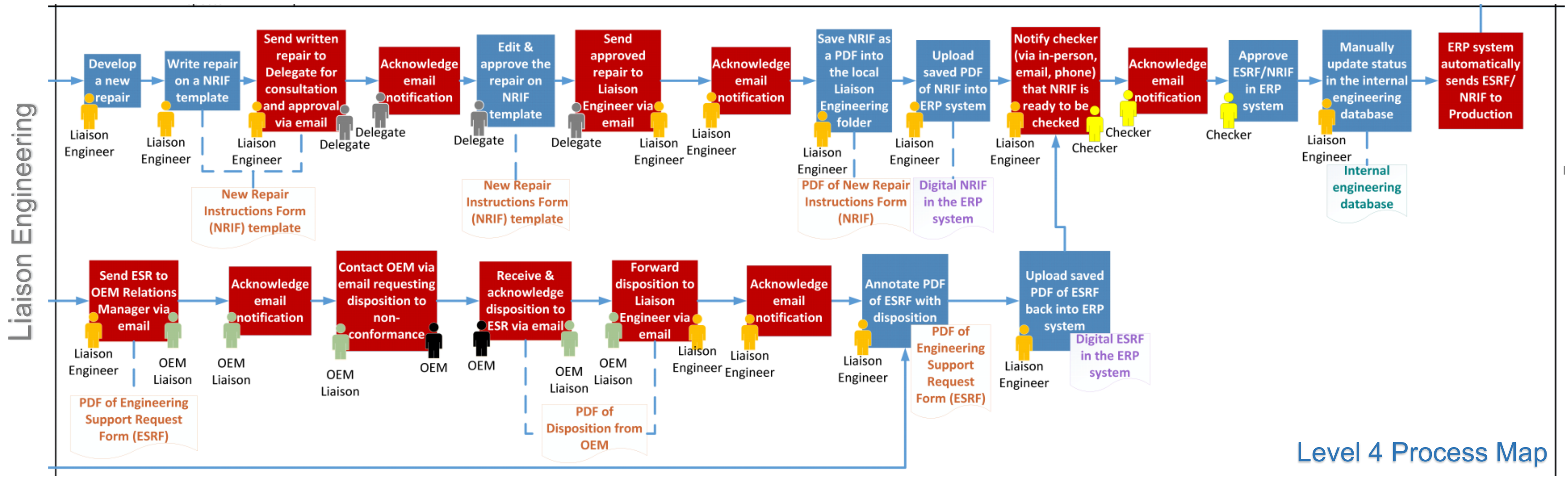
5.5.4. Utility and applicability for stakeholders

The estimated working duration for each activity can provide valuable insights for various stakeholders. Managers can identify time-consuming activities to investigate potential bottlenecks, and plan for better resource allocation and workload management. Managers can also compare the actual working times with the expected durations to identify deviations that may indicate areas to investigate. Additionally, project or program schedules can be estimated or adjusted based on actual performance metrics, which can facilitate the ability to meet project deadlines and stay within budget.

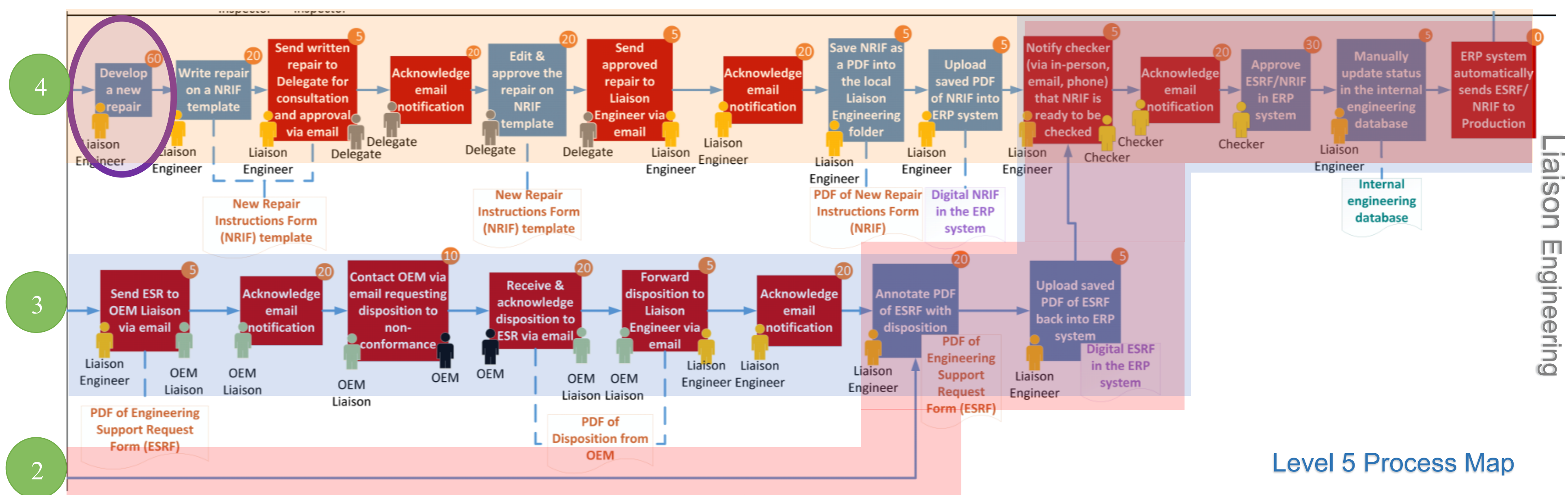
Comparing the process path durations, as outlined in Section 5.5.2, can reveal differences in the time required to complete each path based on the decisions made. This comparison can prompt further investigation into the factors that contribute to these discrepancies. Potential areas for review include task difficulty, the efficiency of communication methods, and resource availability.

Integrating working time with other process metrics, such as communication, artifacts, or roles involved, enables users to understand the process's operational dynamics. Whether it be analyzing communication activities in relation to time, the duration of each role's involvement, or the approximate time spent on each artifact, stakeholders can use this data to identify areas for optimization and implement strategic adjustments. Furthermore, the estimated working duration for each role can be used to help calculate the approximate overall cost of the process by multiplying each roles involvement time by their respective salary.

The Level 5 process map is an example of a current state process map that can serve as a template for future state process mapping exercises. By quantifying the current state approximate duration of each activity organizations can establish benchmarks for performance improvement initiatives. The inclusion of time in process mapping also facilitates scenario planning and predictive modeling for future-state designs. Organizations can simulate the impact of process modification, resource reallocations, or technology integrations on overall process efficiency and effectiveness. This aids in making informed decisions about process redesigns, serving as a comparative framework against which future iterations of process maps can be evaluated. Furthermore, comparing the working time of the current state and future state maps provides a quantitative analysis of potential changes.



(a)



(b)

Figure 21: Comparison of Phase 3 Liaison Engineering swimlane in process maps (a) Level 4 and (b) Level 5.

5.6. Observations

The case study results described in Sections 5.1 through 5.5, serve to validate the methodology proposed in Chapter 4. In addition to demonstrating the different levels of detail and identifying potential stakeholders, the case study results highlight aspects of the process that, while not directly related to the proposed methodology, are valuable for specific applications and showcase the usefulness of the modelling approach.

During the interviews, insights were gained into opportunities for enhancing knowledge-sharing and aligning perspectives between roles. Specifically:

- Liaison engineers and production personnel demonstrated a thorough understanding of their own workflows, with opportunities identified to enhance their knowledge of collaborating departments' processes. Bridging these gaps could strengthen cross-departmental collaboration and support a cohesive approach to organizational objectives.
- The interviews revealed the diverse goals and requirements of different groups, sometimes unaware of potentially competing objectives across departments. For example, the Production department often prioritizes meeting tight deadlines to deliver aircraft repairs or modifications on schedule, whereas the Liaison Engineering department primarily focuses on ensuring technical accuracy. Bringing awareness of these objectives across departments may promote collaboration and process optimization efforts.

The case study also underscored cultural and procedural differences:

- The departments demonstrated some differences in communication styles, terminology, and departmental goals. While these distinctions could result in siloed operations, they can also present an opportunity to leverage diverse perspectives through improved communication and integration.
- Variations between documented procedures and actual workflows revealed adaptive practices which are now identifiable through the process mapping activity presented in this study.

These findings emphasize the dynamic nature of organizational workflows. By gathering information through interviews and organizational artefacts, and capturing actual workflows in process maps, the organization can build a stronger foundation for process improvements, enhance collaboration, and align cross-departmental interactions.

5.7. Discussion

The process maps presented in this study illustrate the interconnectedness and interdependence of the various aspects inherent in organizational workflows. From Level 1 to Level 5, each added level of detail shows how different elements of the process rely on one another to achieve a common goal. These elements including artifacts, roles, communication methods, and time, provide a broader perspective of the process by integrating factors that are often overlooked in traditional process mapping techniques. Collectively, each level of detail depicts a network of interactions and dependencies among activities and departments.

Each level of detail added to the process map demonstrates that no process map is truly independent. Each level reveals new information, allowing users to draw connections between different aspects of the process and how they interrelate. For example, artifacts do not exist on their own, but are created, utilized, communicated and handed-off by various roles through activities in the process. Furthermore, collaboration is demonstrated among roles through hand-offs and communication activities. Details on communication reveal which roles interact and communicate, and how information is managed between roles. The estimated time for each activity, whether a milestone, artifact-related, or communication specific, provides the ability to evaluate any aspect of the process against time. Each level of detail provides a supplementary process perspective. In this case study, the most detailed process map, Level 5, offers a collective and comprehensive depiction of the organization's workflow and its interdependencies.

The findings in this study lead to the following observations with respect to the questions in Chapter 3:

Question 1: How can inter- and intra- departmental collaboration be captured in a process map?

Interdepartmental collaboration is captured across all process map levels, with collaborating departments represented by separate swimlanes. Hand-offs and communication between departments are illustrated by process arrows crossing from one swimlane to another.

Intradepartmental collaboration is demonstrated starting in process map Level 3, where the roles responsible for each activity are annotated onto the map. This illustrates the necessary collaboration and responsibilities within and between departments and roles. In Level 4, the addition of communication methods further highlights how departments and individuals interact and collaborate, providing a more detailed view of the process.

Question 2: What artifacts are used to manage the knowledge associated with a process?

Knowledge is managed and communicated through the 25 artifacts included in the Level 2 process map found in Chapter 5.2. Other internal documents such as process procedures, work instructions, policies and task cards, investigated to help build and validate the process maps, can also be considered as useful for process-related knowledge management. These artifacts collectively document and standardize the process, ensuring that knowledge is captured and transferred effectively within the organization. In this case study, knowledge is also managed and communicated using an ERP system, introduced as a means of communication in the Level 4 process map. Annotating all process-associated artifacts and capturing the means of communication allows map users to track and manage the flow of information and knowledge throughout the process.

Question 3: How can the information flow that is part of an interdepartmental collaboration be shown on a process map?

Information flow in interdepartmental collaboration can be shown on a process map using arrows and connectors that cross swimlanes, representing the transfer of information between departments. Artifacts are annotated next to or linked to each associated activity symbol to illustrate the flow of documents and information. Additionally, the means of communication used, and the roles involved have also been included to detail how information is transferred and to whom.

Question 4: How can the process map be used to clarify the roles and expertise required?

A process map can clarify actors and expertise by annotating each activity with the specific role responsible for its execution. By detailing who performs each task, the map provides a clear view of the expertise required at each step of the process. Introduced in the Level 3 process map, using a person symbol to represent each role responsible for each activity provides insight into the necessary skills and responsibilities to execute the workflow.

Question 5: How can communication methods and tools be identified/represented in a process map?

Communication, as a factor of affecting collaboration and necessary for handing-off or transmitting knowledge or information, is integrated into the Level 4 process map between existing activities wherever it occurs. To differentiate between an activity and a communication-specific activity, all communication-specific activity symbols are represented by a different colour. This distinction adds clarity, highlighting where and how information is exchanged throughout the process. The process map includes a total of 40 communication activities and 52 task-based activities, along with 3 subprocess symbols. This count excludes all activities identified within the three subprocesses illustrated in the map.

Question 6: Can process maps be used to identify gaps and overlaps at the various levels of detail of a multidisciplinary process?

Throughout the data collection, building, validating, and evaluation phase of process mapping, areas where responsibilities are unclear, or tasks are duplicated or missing may be revealed. The identification of potential gaps and overlaps in the process is possible at any level of detail. Having all necessary information to evaluate a process allows users to assess the process and evaluate if it its structured efficiently and purposefully for the organization's needs.

Question 7: Does including artifacts, roles, communication tools, and hands-on time in a process map reveal information that would not typically be available from a task-focused process map?

Including artifacts, roles, communication tools, and working time in a process map reveals dependencies, hand-offs, and the collaboration required to complete tasks. This comprehensive view goes beyond a task-focused map by illustrating the context of task execution, the resources required, and interactions between process components. It provides a more complete understanding of the workflow.

Question 8: What levels of process mapping detail are most useful for specific end users or purposes?

The observed usefulness of each level of detail in this case study are as follows:

Level 1 process map - Milestones: Useful for users interested in visualizing and understanding overall process workflow within and across collaborating departments and identifying major process phases and milestones.

Level 2 process map - Artifacts: Useful for users interested in visualizing and understanding process workflow and information flow within and across collaborating departments. Including artifacts to a process map enables map users to identify artifacts used, their transformation throughout the process, and provides a visual traceability tool.

Level 3 process map - Roles: Useful for users interested in visualizing and understanding process workflow within and across collaborating departments, alongside roles and responsibilities of the actors involved. Including individual roles in the workflow allows map users to identify the actors responsible for executing each task, and the tasks requiring special credentials or access.

Level 4 process map - Means of Communication: Useful for users interested in visualizing and understanding process workflow and communication flow within and across collaborating departments. Including communication details reveals to map users any behavioural and organizational communication patterns within or across departments, and between various roles.

Level 5 process map - Time: Useful for users interested in visualizing and understanding process workflow within and across collaborating departments, alongside the working-time to complete each activity. Including the estimated working time of each activity allows map users to identify time-consuming tasks, evaluate the various process outcomes based on the different decisions, and assess time spent on specific artifacts, actors and roles, or communication activities.

Chapter 6. Conclusion

Process mapping is a versatile technique that can be adapted to demonstrate the sequence of work along with other relevant process-related information tailored to the end users' needs. This case study, involving five process maps with varying levels of detail, demonstrates the impact of including specific information related to the process in a process map. It also highlights how the usefulness of each level of detail varies for different users or stakeholders.

The integration of different levels of detail – activities, artifacts, roles, communication methods, and estimated working time – into process maps can be customized according to the industry, process requirements, and the relevance of process-related information. Organizations should consider the time investment required for a detailed current-state process evaluation, as more detail necessitates additional effort for data collection and analysis. Stakeholders can select the most appropriate combination of details to gain insights into workflow dynamics, ensuring alignment with their objectives.

Chapter 7. Future Work

A recommended next step for this research is to apply the developed methodology to another case study, testing its adaptability and generalizability across different processes and organizational contexts.

For this particular case study, a key recommendation is to analyze specific areas for improvement within the process maps at each detail level. Additionally, using current-state process maps as templates for exploring future-state scenarios could enable comparative analysis between different levels of detail and their impact on process improvement.

Future investigations should also examine whether this process mapping methodology can serve as a strategic framework for continuous improvement, beyond the descriptive capabilities presented in this study. Engaging stakeholders in future research should also be considered to gather their perspectives on the identification of potential process improvements, recommendations for streamlining process, and ensuring all necessary activities are effectively covered and tailored to specific process contexts.

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Appendices

Appendix A: First-round interview guided questions

Questions for liaison engineers

1. What is your role?
2. How do you know when there is a new non-conformance raised or an Engineering Support Request (ESR)?
3. Who oversees assigning engineers to an ESR?
4. Can an engineer assign themselves to an ESR?
5. Are the engineers in the Liaison Engineering department divided by program?
6. What is the first thing you do when an ESR is assigned to you?
7. What information is required by the Production department for you to fully understand the request or issue?
8. What are the most common issues faced when resolving an ESR?
9. Have you ever suggested a change to the process of raising and/or dispositioning a non-conformance? If so, was it implemented?
10. What part of this process is most important/relevant to you?
11. Is there any part of the process you deem unnecessary or unimportant, and why?
12. From your perspective, what is the interaction like with Production?

Questions for delegate

1. What is your job title?
2. What does your job entail?
3. How do you interact with the system in which ESRs are reported and Dispositions are provided?
4. What instance(s) are you called in to address an ESR?
5. What are the most common issues you face when resolving an ESR/non-conformance?
6. Can you give me an example of something in the process that hasn't gone well?
7. What part of the process do you deem important?
8. Is there any part of the process you deem unnecessary or unimportant?

Questions for liaison engineering lead

1. What is the first thing you look for or do when a new ESR comes in?
2. What information do you need from the Production Department to fully understand the request or issue?
3. When are you required to do "triage"?
4. Can liaison engineers assign themselves to an ESR?
5. If an ESR is taking longer to resolve than the estimated or required time, is there someone that verifies if the assigned person needs assistance?

Questions for operations manager, and crew leads:

1. What is your role?
2. Did you work with the paper based ESR process before it was digitized into the system?

3. Can you give me some examples/instances of what typically is considered an ESR?
4. Can you walk me through your interaction with the system?
5. Are there things you like or don't like about the system?
6. Who typically reports an issue/problem found?
7. Who's authorized to fill out a new ESR?
8. Who's authorized to submit the ESR to the Engineering department?
9. Do you approve/check the ESR before sending it to the Engineering department?
    i. If so, what do you look for?
    ii. What information do you deem important to be included?
    iii. How do you decide what information to include?
10. If you had to change something about the system, what would it be and why?
11. Specifically for reporting issues and requesting engineering support, are there processes/procedures you refer to?
    i. If so, are there different processes for difference programs/customers?
12. Do you receive automated emails when you receive a response from the Liaison Engineering department?
13. What are the next steps when receiving repair instructions or a disposition?
    i. Do you assign some to it? If so, how and where?
14. Is there a difference between receiving repair instructions and a disposition?
15. When do you deem it necessary to respond or comment on the received disposition or repair instructions? Only when you cannot accomplish a specific task?
16. When is the ESR officially closed?
    i. Must someone verify/check it?
17. What are common issues you face when reporting and closing an ESR (if any)?
18. On average, how long does it take to gather all the information of the problem/issue being reported as an ESR (e.g. take pictures, location, size measurements)?
    i. How long does it take to get it approved before submitting to the Liaison Engineering department?
19. Can you give me an example of something in the process that hasn't gone well?
20. What part of the process do you deem most useful?
21. Is there any part of the process you deem unnecessary or unimportant?

Questions for technicians

1. What is your specialty?
2. Did you work with the paper based ESR process before it was digitized into the system?
3. Can you give me some examples/instances of what typically is considered an ESR?
4. Can you walk me through your interaction with the system?
5. Are there things you like or don't like about the system?
6. Who typically reports an issue/problem found?
7. Who's authorized to fill out a new ESR?
8. Who's authorized to submit the ESR to the Engineering department?
9. Do you approve/check the ESR before sending it to the Engineering department?
    i. If so, what do you look for?

ii. What information do you deem important to be included?
iii. How do you decide what information to include?

10. If you had to change something about the system, what would it be and why?
11. Specifically for reporting issues and requesting engineering support, are there processes/procedures you refer to?
    i. If so, are there different processes for difference programs/customers?
12. Do you receive automated emails when you receive a response from the Liaison Engineering department?
13. Who assigned you to complete the repair instructions or a disposition?
    i. How do they inform you of a new disposition or repair instructions?
14. Is there a difference between receiving repair instructions and a disposition?
15. Are you authorized to respond or comment on the received disposition or repair instructions when you cannot accomplish a specific task?
16. When is the ESR officially closed?
    i. Must someone verify/check it that your work is complete, and correct?
17. What are common issues you face when reporting and closing an ESR (if any)?
18. On average, how long does it take to gather all the information of the problem/issue being reported as an ESR (e.g. take pictures, location, size measurements)?
    i. How long does it take to get it approved before submitting to the Liaison Engineering department?
19. Can you give me an example of something in the process that hasn't gone well?
20. What part of the process do you deem most useful?
21. Is there any part of the process you deem unnecessary or unimportant?

Appendix B: Second-round interview guided questions

Questions for Production crew leads and technicians

General questions

1. When you input the job number into the system, does it automatically input the unique identifier for the engineering support request?
2. What fields are automatically filled out in the system and/or which fields are you required to manually fill out when raising a new non-conformance/engineering support request?
3. If the creator of the new non-conformance is an SME and assigns a primary approver and back up approver, does everyone they assigned get an automated email notification saying they were assigned to it, or the creator must notify each person themselves?
4. Can the creator of the newly raised non-conformance press the "Approved, Send to Engineering" or does it have to be done by the Primary Approver (crew lead)?
5. Throughout the process, who gets the automated email notifications that a disposition has been uploaded to the system by Engineering?
6. When are you required to press "button A" and "button B" in the system?
7. Do you always have to press "button A" even if you completed all the steps and don't need an alternative procedure or you would press Production close?
8. What happens when a step in the disposition can't be completed?
9. Does it ever happen that a disposition is released, and you are not able to complete it, or deviations occurred? What happens then? How would you request engineering support? Can you press "button A" or do you have to raise a new engineering support request?
10. Who is authorized to press "button B"?
11. Once you've pressed "button B", is the engineering support request completely done or must you revisit it at some point?

Process related questions

1. When Engineering releases a disposition, how does it get to Production in a physical or digitized form?
2. What happens to the physical paper trails (e.g. of the disposition) within the Production environment?
3. Must you submit the signed-off disposition?
4. Does the disposition need to be filed with the task card and work order?
5. Who is authorized to sign-off the disposition?
6. Who is authorized to forward the signed-off disposition to record-keeping?
7. How do you demonstrate to Engineering that a steps in a disposition have been accomplished?
8. What formatting process (paper or digital) does a raised non-conformance and disposition go through? How is it stored throughout the process?
9. Is there a checklist for closing a task card?
10. Who completes the audit? Is there a checklist for that? What are they verifying?

Sign-off/approval related questions

1. Sign offs on completed steps in a disposition must be done by an Aircraft Certification Authority (ACA) Holder. Who can be an ACA holder? What qualifications is he/she required to have? Does he/she physically go check and approve the signed off repair instructions? Can a crew lead do it?
2. When is the crew lead required to sign off on the completed steps of a disposition?
3. Who can update the status in the system that a disposition has been completed?
4. Are you ever required to scan and upload the signed off disposition back into the system? If yes, when?
5. Who is authorized to be a primary and backup approver in the system?

Questions for liaison engineers

1. How does engineering review/check that a disposition has been accomplished by Production with no deviations?
2. How does engineering review/check that repair instructions have been accomplished by Production with no deviations?
3. How do you communicate to the approver a New Repair Instructions closing document needs to be signed/checked in the system?
4. When you must get a checklist reviewed/checked and signed, who do you ask and how do you communicate that it needs to be signed/checked?
5. How is the level of authority decided in the Liaison Engineering department?

Appendix C: Description of information artifacts

A description of the specific artifacts and information found in this case study's process are as follows:

Digital information internal to the ERP system (purple):

1. ***Digital Engineering Support Request (ESR) in ERP system***:
    a. An electronic record utilized to initiate and document requests for engineering assistance or support by the Production department.
    b. Typically encompasses all pertinent information about a problem, issue, or non-conformance necessitating resolution or attention from the Liaison Engineering team.
    c. Contents commonly include:
        i. Structural repair requests for damages beyond the scope of existing aircraft manuals (e.g., structural repair manual) or deviations from approved repairs.
        ii. Aircraft component structural details provided through original equipment manufacturer (OEM) drawings.
        iii. Process specifications referenced in OEM drawings.
        iv. Part number specifics and/or applicability.
        v. Alternative part number or material specifications.
        vi. Identification of system function discrepancies.
2. ***Digital information about problem/issue in ERP system***:
    a. Contains details entered by the ESR creator in the ERP system regarding the identified problem/issue/non-conformance.
    b. Includes unique ESR identifier, creation date, creator's name, employee identification (ID), department, project ID, task card number, and damage description.
    c. The information is digitally stored within the ERP system.
3. ***Digital ESRF in the ERP system***:
    a. The uploaded PDF of the Engineering Support Request Form (ESRF) in the ERP system transforms into a digital record within the ERP system, facilitating inter-departmental sharing.
4. ***Digital NRIF in the ERP system:***
    a. The PDF of the New Repair Instructions Form (NRIF) is uploaded to the ERP system under the corresponding ESR unique identifier, existing as a digital document for access by the Production department.
5. ***Signed completed steps as Digital ESRF or NRIF in the ERP system:***
    a. Once the completed steps on the ESRF or NRIF have been signed and saved as a PDF, the Production department can upload it into the ERP system.
    b. This process creates a digital copy of the ESRF or NRIF with completed steps signed, within the ERP system, shareable with the Liaison Engineering Department.

6. ***Production comments as digital information in ERP system:***
    a. If the Production department cannot complete the disposition or instructions provided by Liaison Engineering, they must document a description and reasoning for the incomplete or deviated tasks.
    b. Authorized Production personnel must add these comments directly under the appropriate ESR in the ERP system.
7. ***Digital NRIF closing document in the ERP system:***
    a. The PDF of the NRIF Closing Document becomes a digital file in the ERP system upon upload by the Liaison Engineering department, enabling sharing with the Production department for required signatures.
8. ***Signed Digital NRIF closing document in the ERP system:***
    a. The signed PDF of NRIF closing document allows the authorized Production personnel to upload it into the ERP system.
    b. This process generates a Signed Digital NRIF Closing Document in the ERP system, sharable with the Liaison Engineering department.
9. ***Signed Digital ESRF in the ERP System***
    a. The signed PDF of the ESRF allows the authorized Production personnel to upload it into the ERP system.
    b. This process generates a final Signed Digital ESRF in the ERP system, shareable with the Liaison Engineering department.

Digital documents in PDF or Word formats (orange):

1. ***New Repair Instructions Form (NRIF) template:***
    a. A template located on the shared drive within the Liaison Engineering department.
    b. Used to develop and approve a new repair for issues/problems/non-conformances.
    c. Structures as a Word document, featuring predetermined fields for population by a liaison engineer, including ESR unique identifier, issue date, aircraft details, repair description, and individual repair/instruction steps.
    d. Allocated sign-off sections for a Mechanical Aircraft Maintenance Engineer (AME) and Inspector are incorporated for each repair/instruction step.
    e. Subsequent parts of this template may be required if the provided repair instructions can’t be completed from the instructions previously provided in a NRIF.
2. ***PDF of New Repair Instructions Form (NRIF):***
    a. The populated Word document template of the NRIF is converted into PDF format.
    b. Requires saving onto the Liaison Engineering drive for further processing.
3. ***PDF of Disposition from OEM:***
    a. A PDF document provide by the OEM outlining the disposition for the issue/problem/non-conformance.
    b. Required in instances where no existing approved data or repairs are available, and the OEM serves as the designated design authority.

4. ***PDF of Engineering Support Request Form (ESRF)***:
    a. Generated as a PDF document within the ERP system via the “print to PDF” function.
    b. Captures relevant digital information previously entered in the ERP system into a predefined PDF template.
    c. Requires saving onto the Liaison Engineering drive for further processing.
    d. Features a disposition section, utilized solely when existing approved data is present.
    e. Signatures from an authorized engineer and production crew lead are necessary upon completion of the written disposition.
5. ***Signed completed steps on PDF of ESRF or NRIF***
    a. Once authorized Production personnel manually sign-off on the completed steps of the Printed ESRF or NRIF document, they scan it and save it as a PDF document.
    b. This process creates a digital file of the signed steps on the ESRF or NRF on their computer.
6. ***PDF of New Repair Instruction Form (NRIF) closing document:***
    a. A PDF summarizing the completed repair and its basis for approval, created upon completion of the provided disposition for an issue/problem/non-conformance with no existing approved data.
    b. Includes pertinent information about the issue/problem, completed repair details (with or without deviations), and a predefined checklist requiring a Production department-approved person to sign-off for ESR closure.
7. ***Signed PDF of NRIF closing document***
    a. Once authorized Production personnel manually sign-off the Printed NRIF closing document, they scan it and save it as a PDF document.
    b. This process creates a digital file of the signed NRIF closing document on their computer.
8. ***Signed PDF of ESRF:***
    a. Once authorized Production personnel manually sign-off ESRF document, they scan it and save it as a PDF document.
    b. This process creates a digital file of the signed ESRF on their computer.
9. ***PDF of Minor repair form (MRF):***
    a. Used for signing-off data when a repair is classified as Minor rather than Major.
    b. This is considered acceptable data and not approved data.
10. ***Checklist Template in Word document:***
    a. A predetermined procedural checklist template utilized to verify the completion of all necessary steps and documentation before ESR closure.
    b. Features a column for liaison engineer’s initials and date signed alongside checklist steps.
    c. Features an allocated field for checker’s signature.
11. ***Checklist PDF:***

   a. Once completed, the filled-out checklist is saved as a PDF document in the appropriate Liaison Engineering folder.

Physical paper documents (green):

1. ***Printed New Repair Instructions Form (NRIF):***
   a. The digital NRIF supplied in the ERP system by the Liaison Engineering department is printed by the Production department for manual sign-off on repair or instruction steps.
2. ***Printed Engineering Support Request Form (ESRF):***
   a. The digital ESRF supplied in the ERP system by the Liaison Engineering department is printed by the Production department for manual sign-off on the completed disposition.
3. ***Work Order document***:
   a. A physical paper-based document detailing specific tasks, instructions, and maintenance requirements for aircraft components or systems.
   b. Includes part details, quantity, technical specifications, required materials, tools equipment, quality standards, and any special instructions.
   c. Serves as a communication tool between different departments or teams involved in the manufacturing process, ensuring that tasks are completed efficiently and accurately according to established procedures.
4. ***Printed New Repair Instructions Form (NRIF) closing document:***
   a. The Digital NRIF Closing Document is printed by the Production department for manual sign-off in requested fields.

Digital information external to the ERP system (turquoise):

1. ***Internal engineering database:***
   a. An internal database utilized by the Liaison Engineering department to keep track of all ESRs and their status
   b. Also used as a searchable repository to easily identify ESR ID numbers for specific programs and similar non-conformances.

Appendix D: Level 1 process map figures

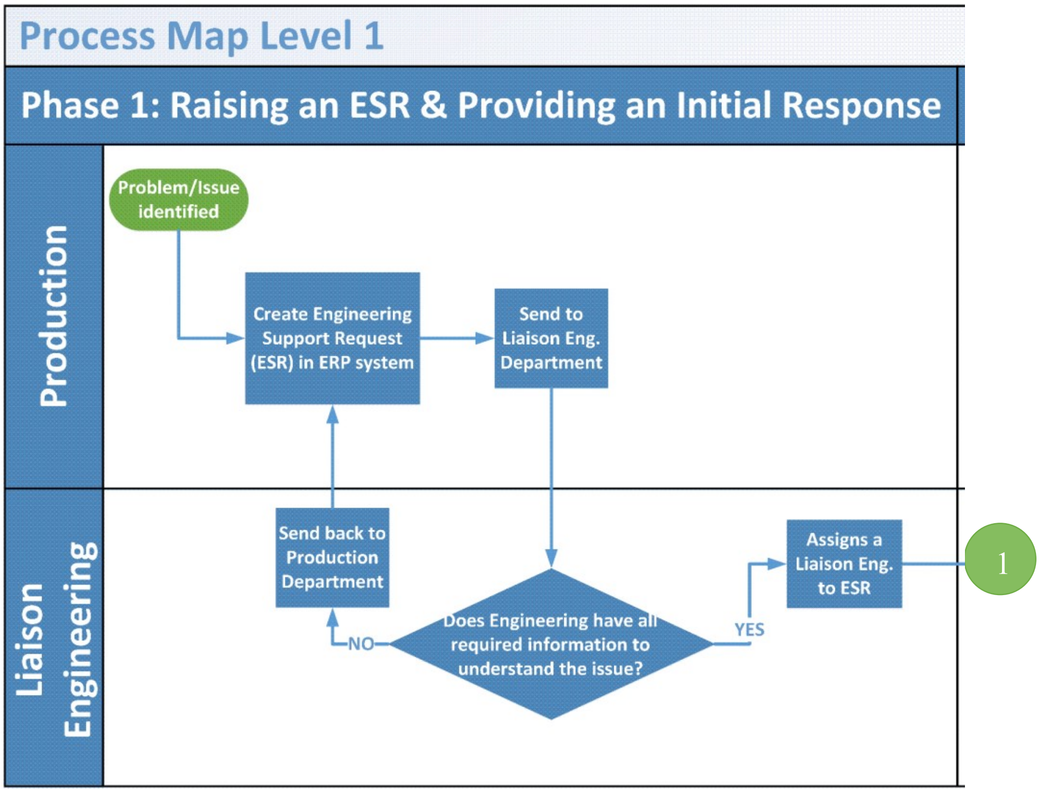

Figure A. 1: Phase 1 of the Level 1 process map.

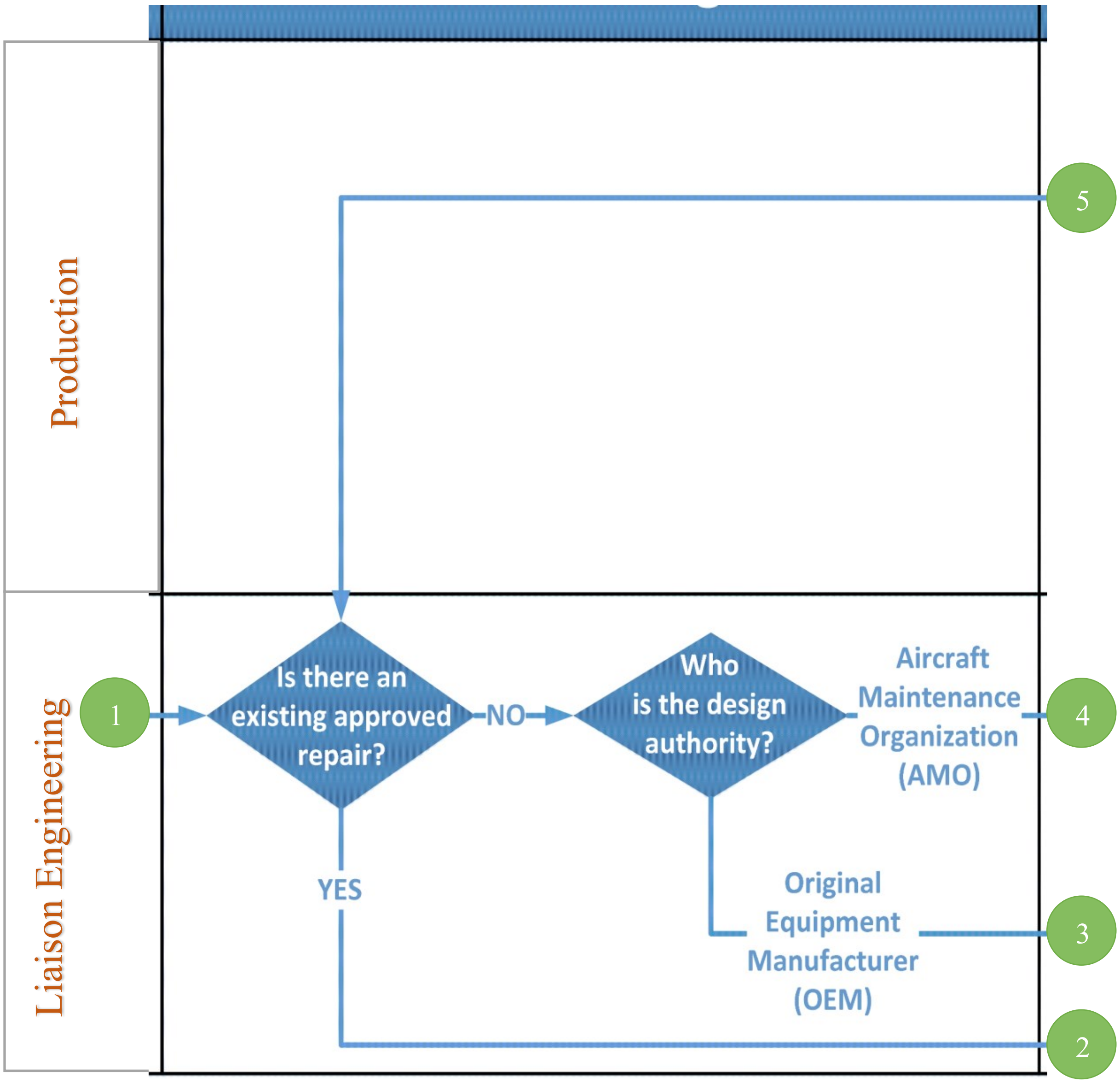

Figure A. 2: Phase 2 of the Level 1 process map.

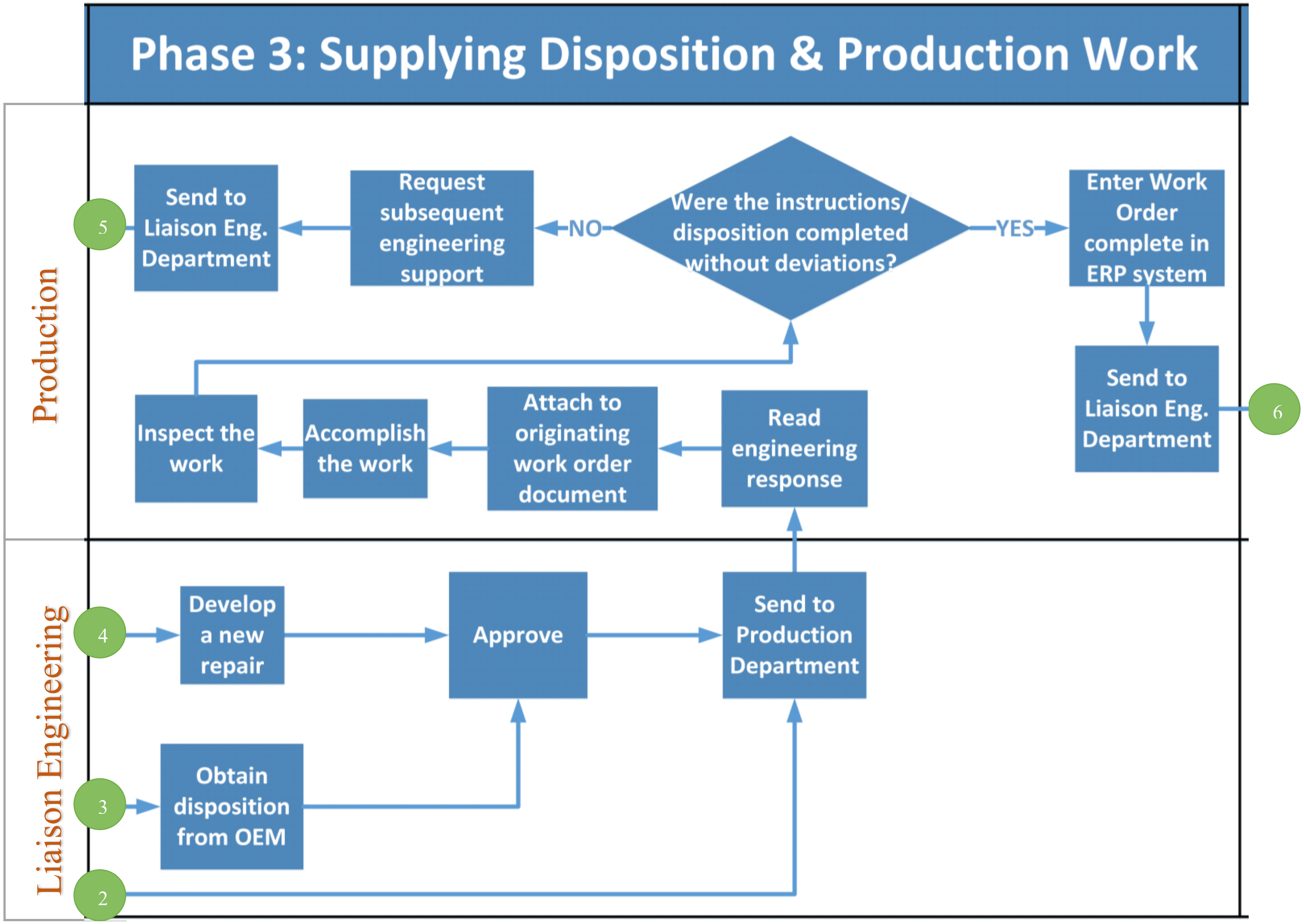

Figure A. 3: Phase 3 of the Level 1 process map.

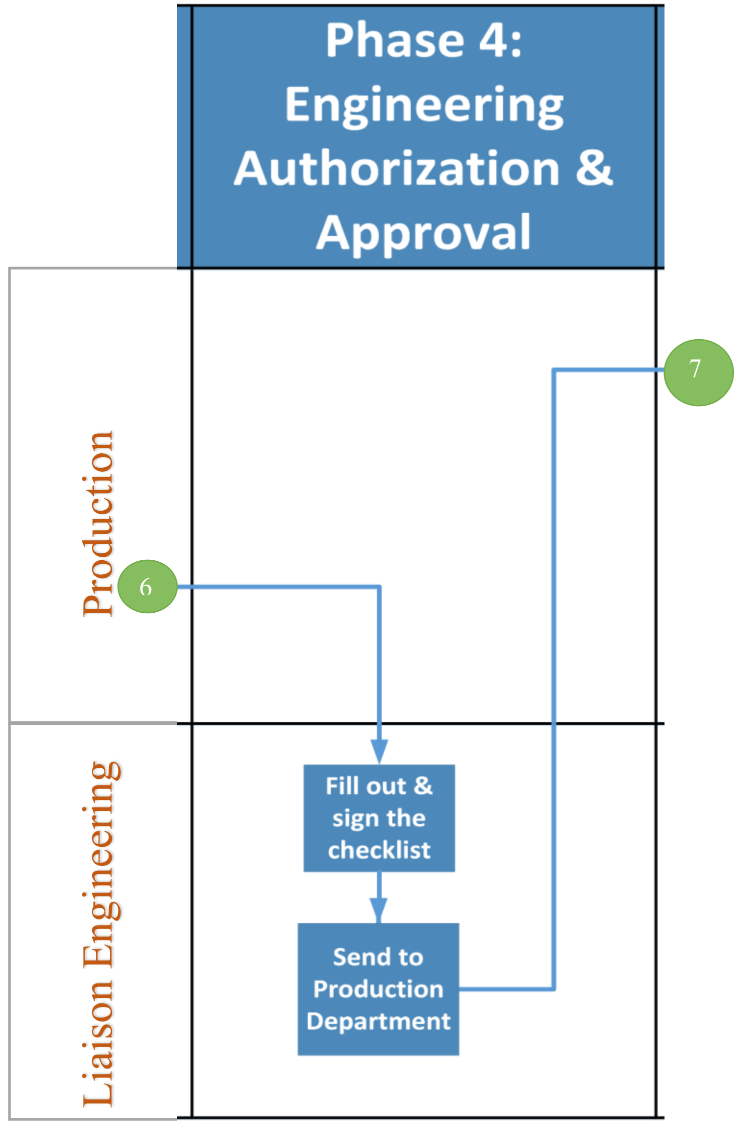

Figure A. 4: Phase 4 of the Level 1 process map.

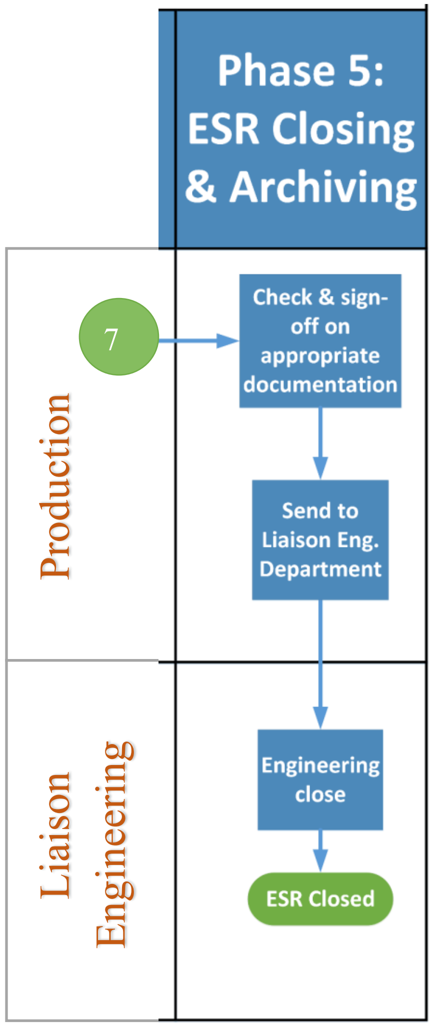

Figure A. 5: Phase 5 of the Level 1 process map.

Appendix E: Level 2 process map figures

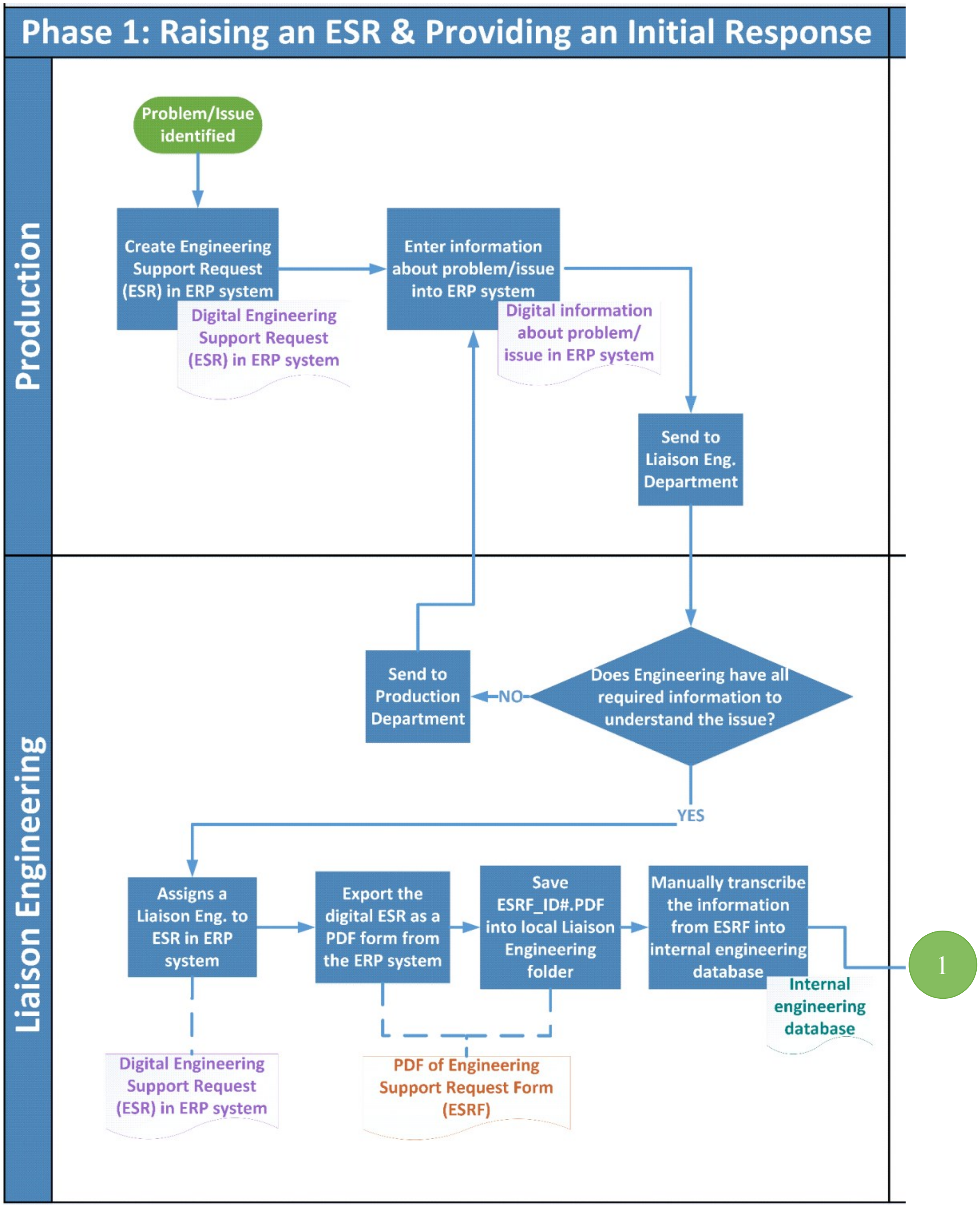

Figure A. 6: Phase 1 of the Level 2 process map.

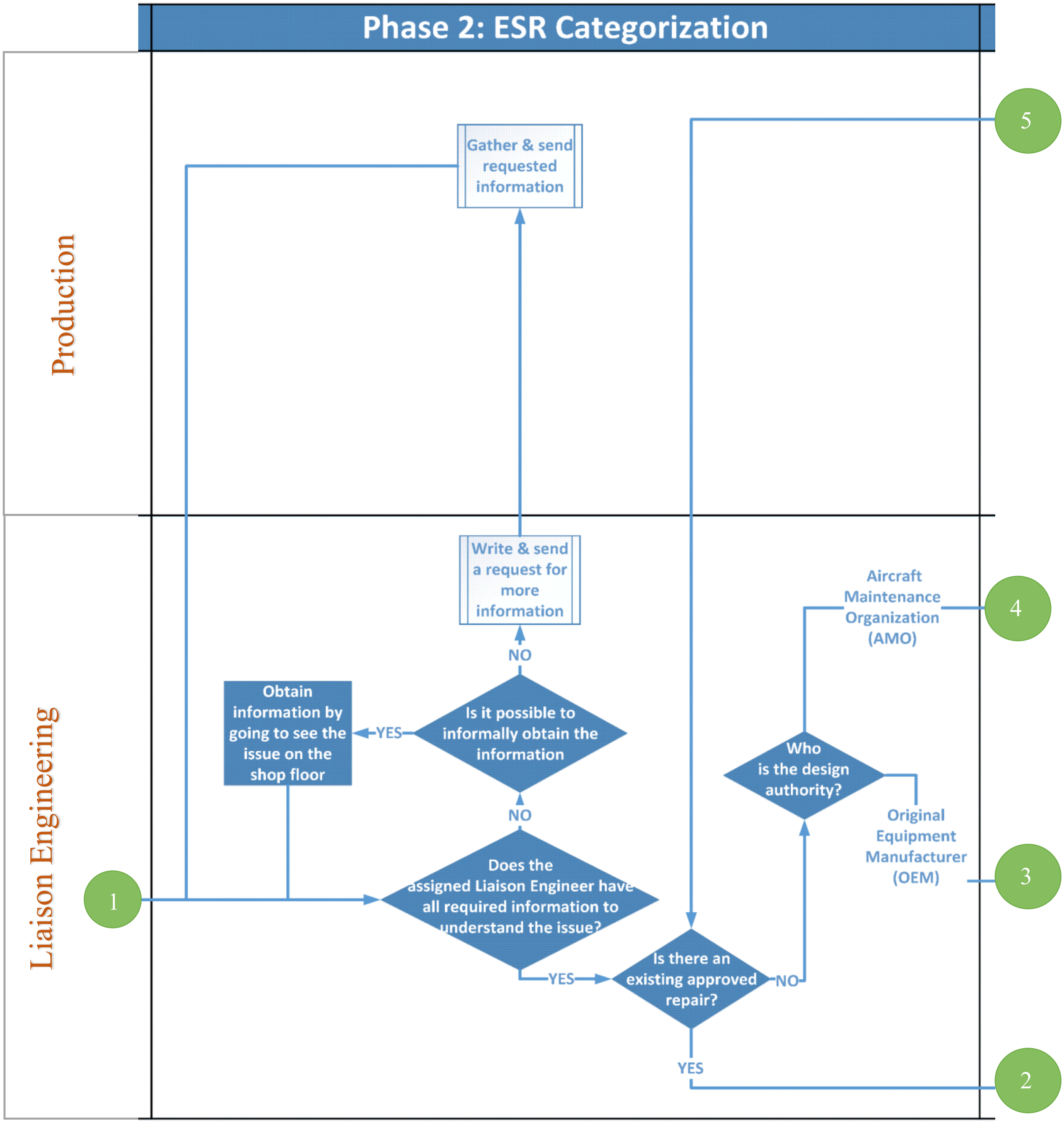

Figure A. 7: Phase 2 of the Level 2 process map.

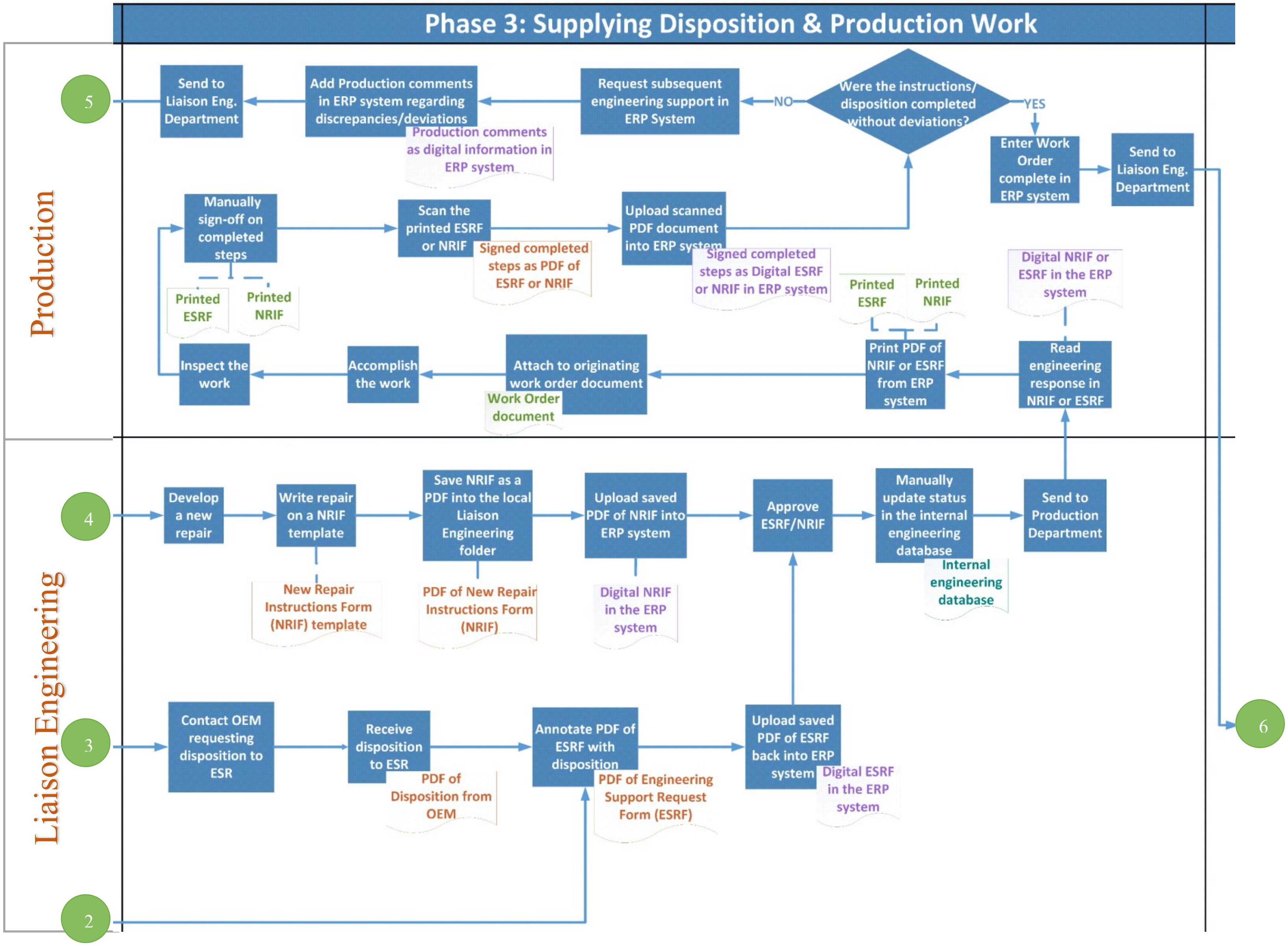

Figure A. 8: Phase 3 of the Level 2 process map.

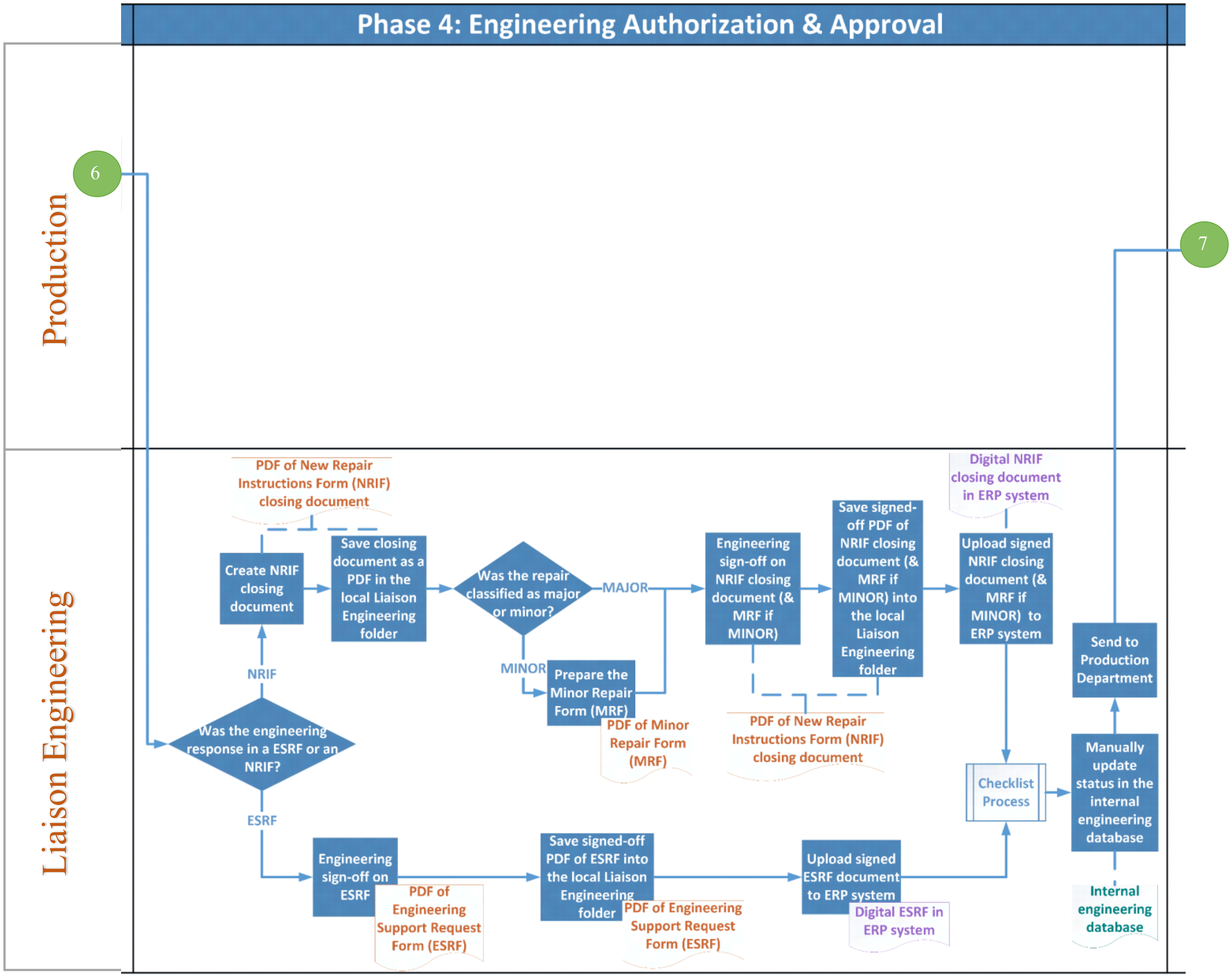

Figure A. 9: Phase 4 of the Level 2 process map.

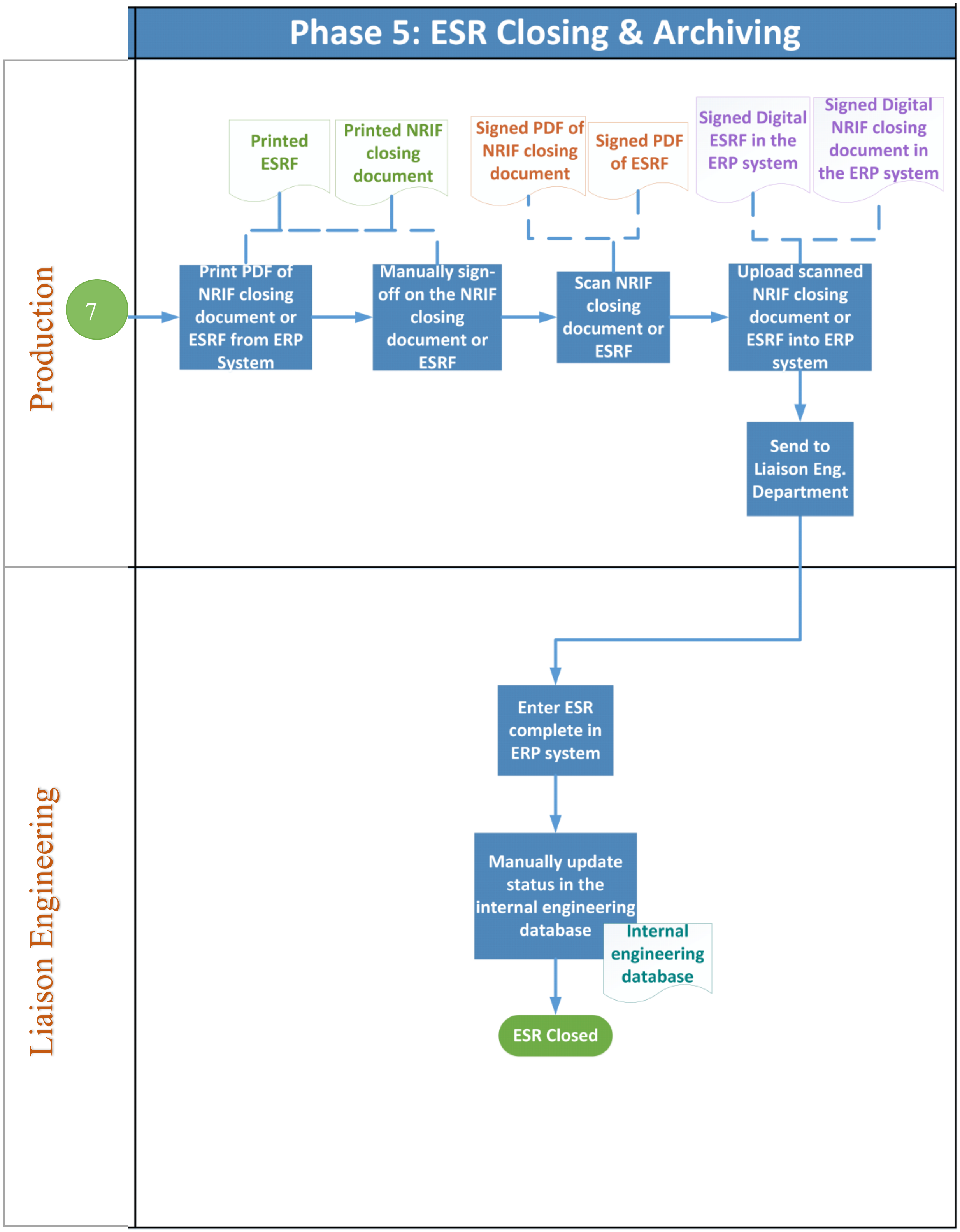

Figure A. 10: Phase 5 of the Level 2 process map.

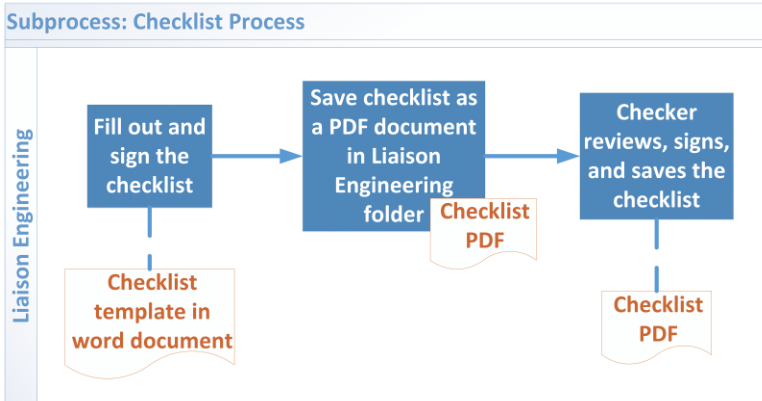

Figure A. 11: Subprocess "Checklist Process" in the Level 2 process map.

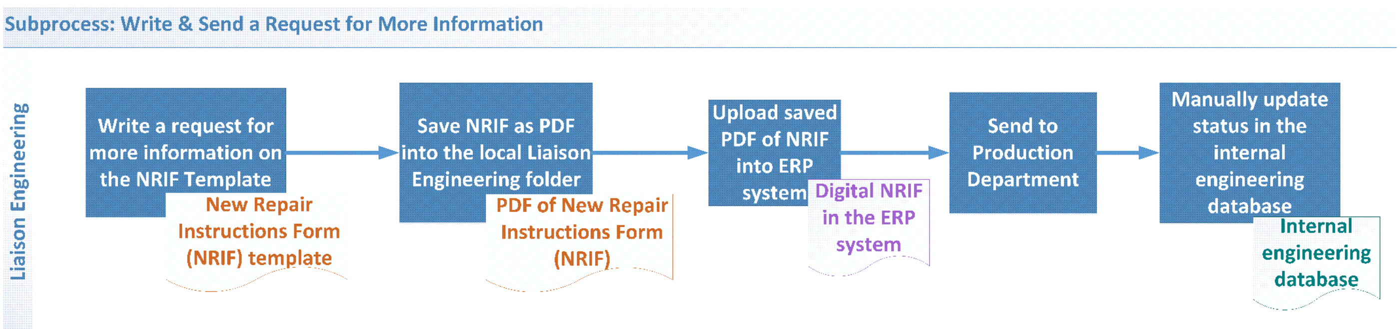

Figure A. 12: Subprocess "Write & Send a Request for More Information" in the Level 2 process map.

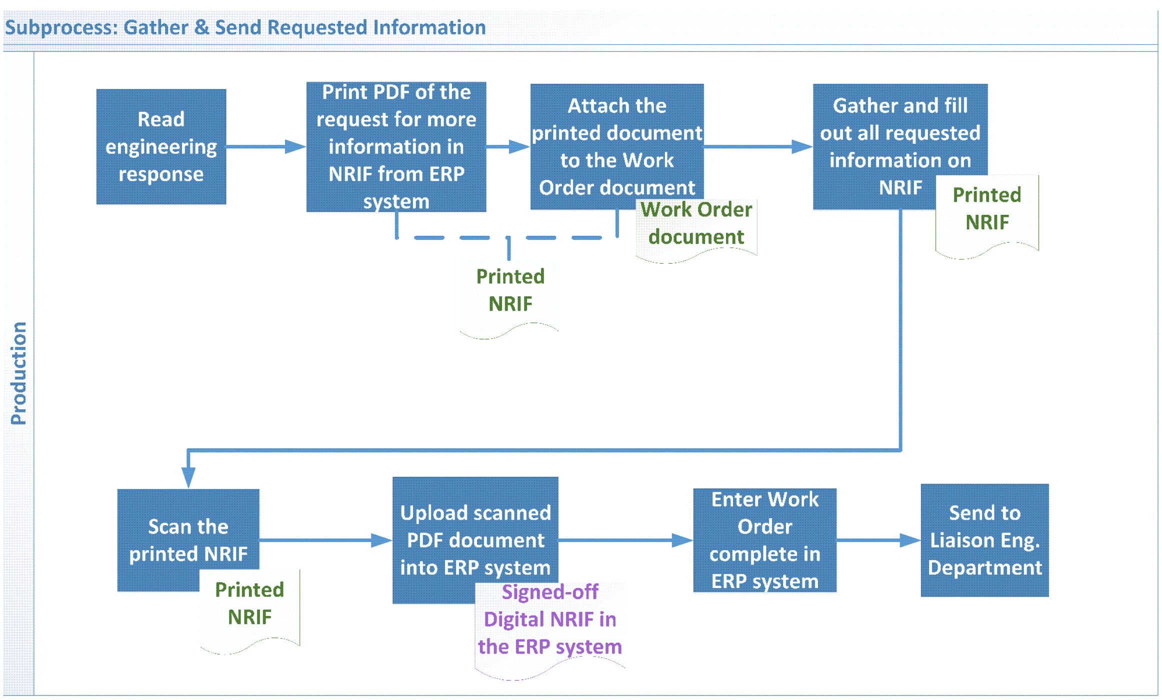

Figure A. 13: Subprocess "Gather & Send Requested Information" in the Level 2 process map.

Appendix F: Level 3 process map figures

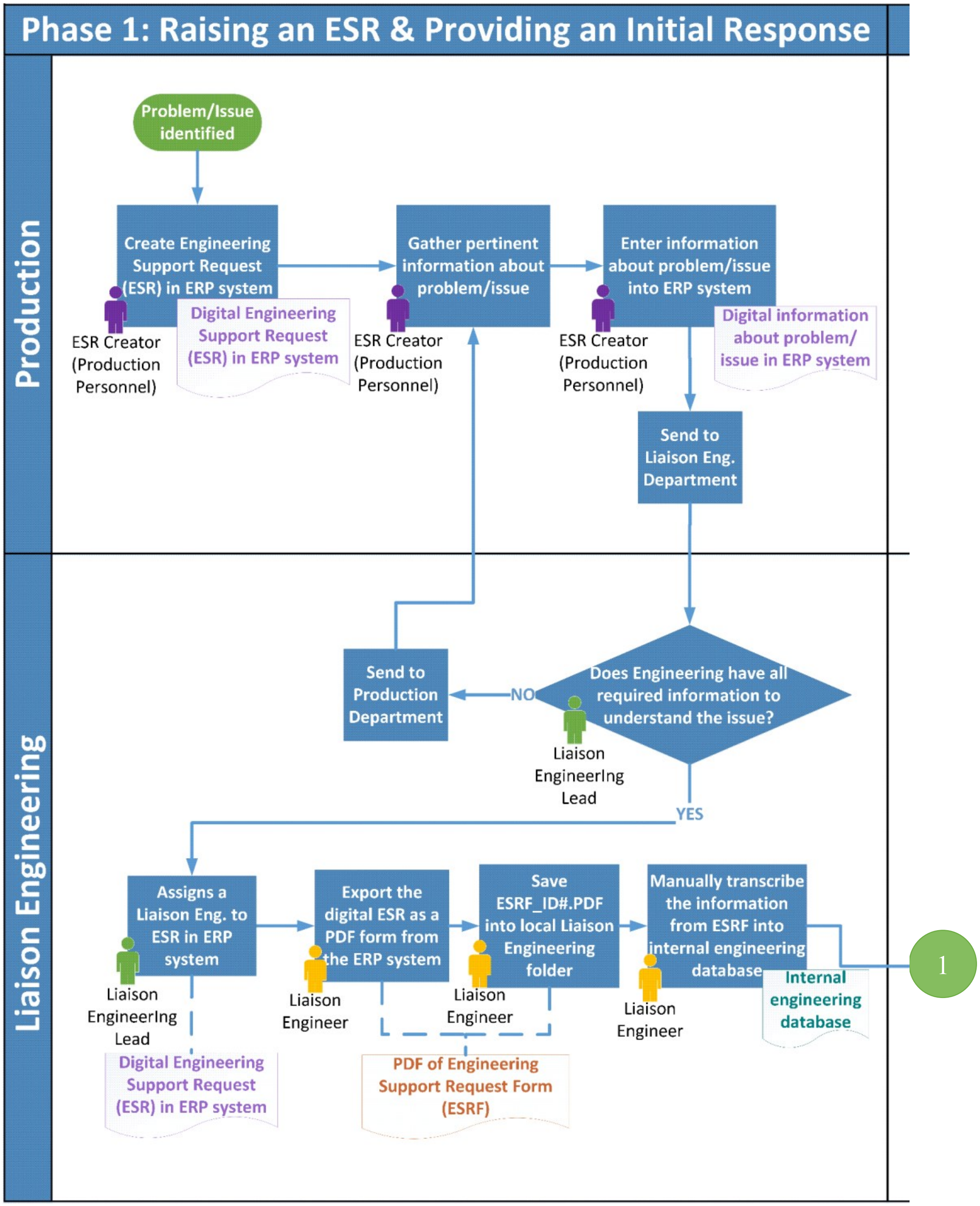

Figure A. 14: Phase 1 of the Level 3 process map.

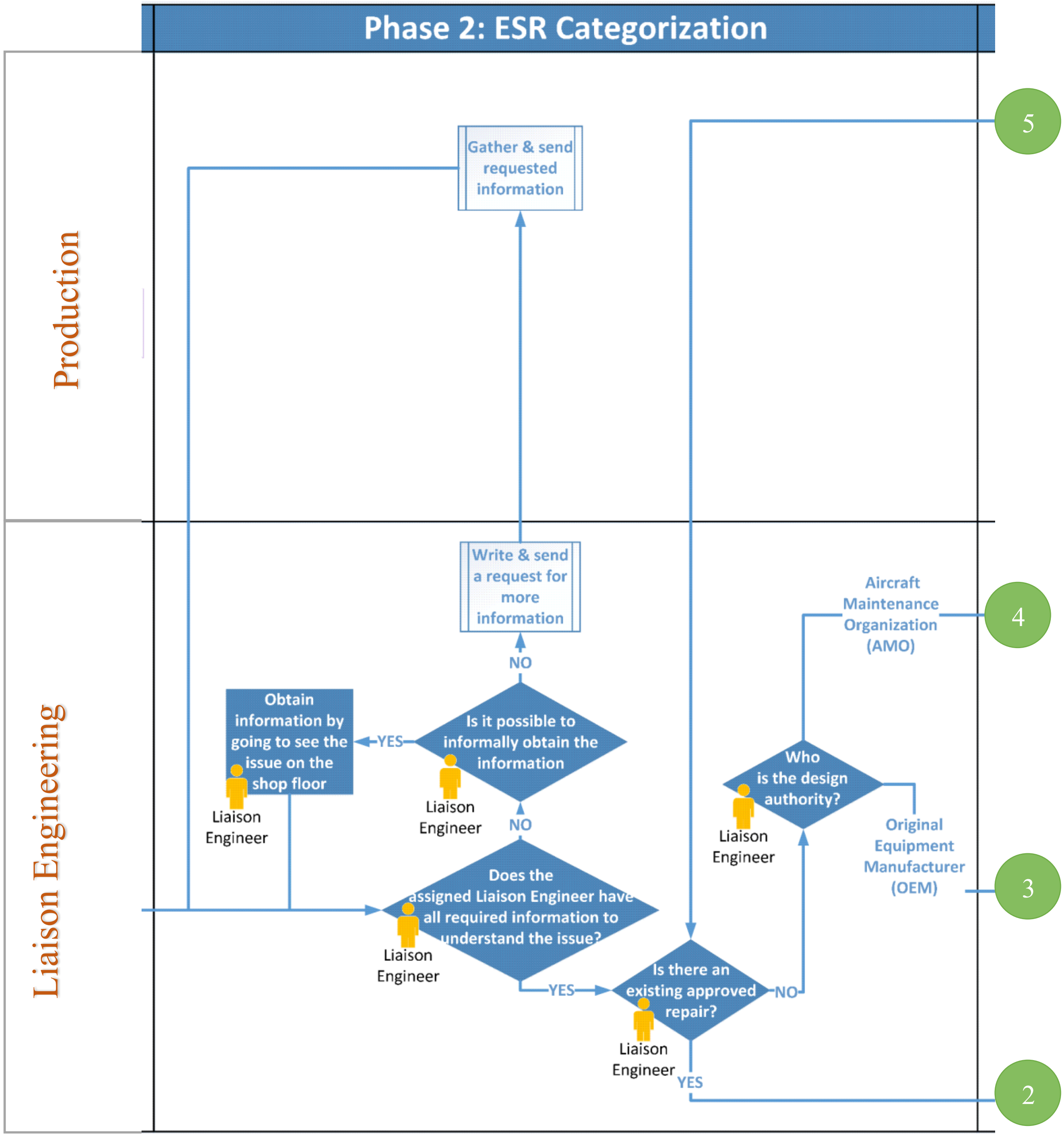

Figure A. 15: Phase 2 of the Level 3 process map.

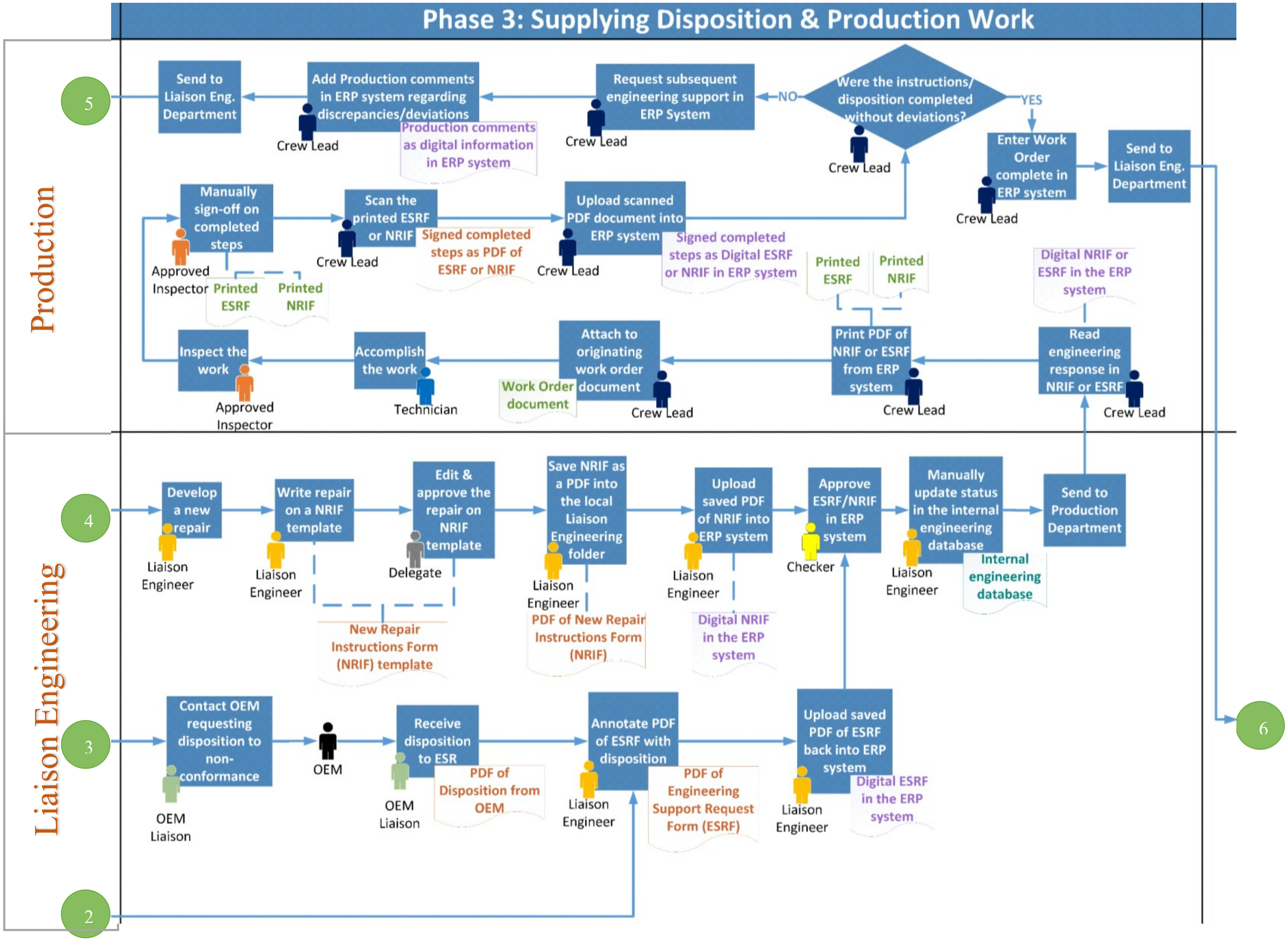

Figure A. 16: Phase 3 of the Level 3 process map.

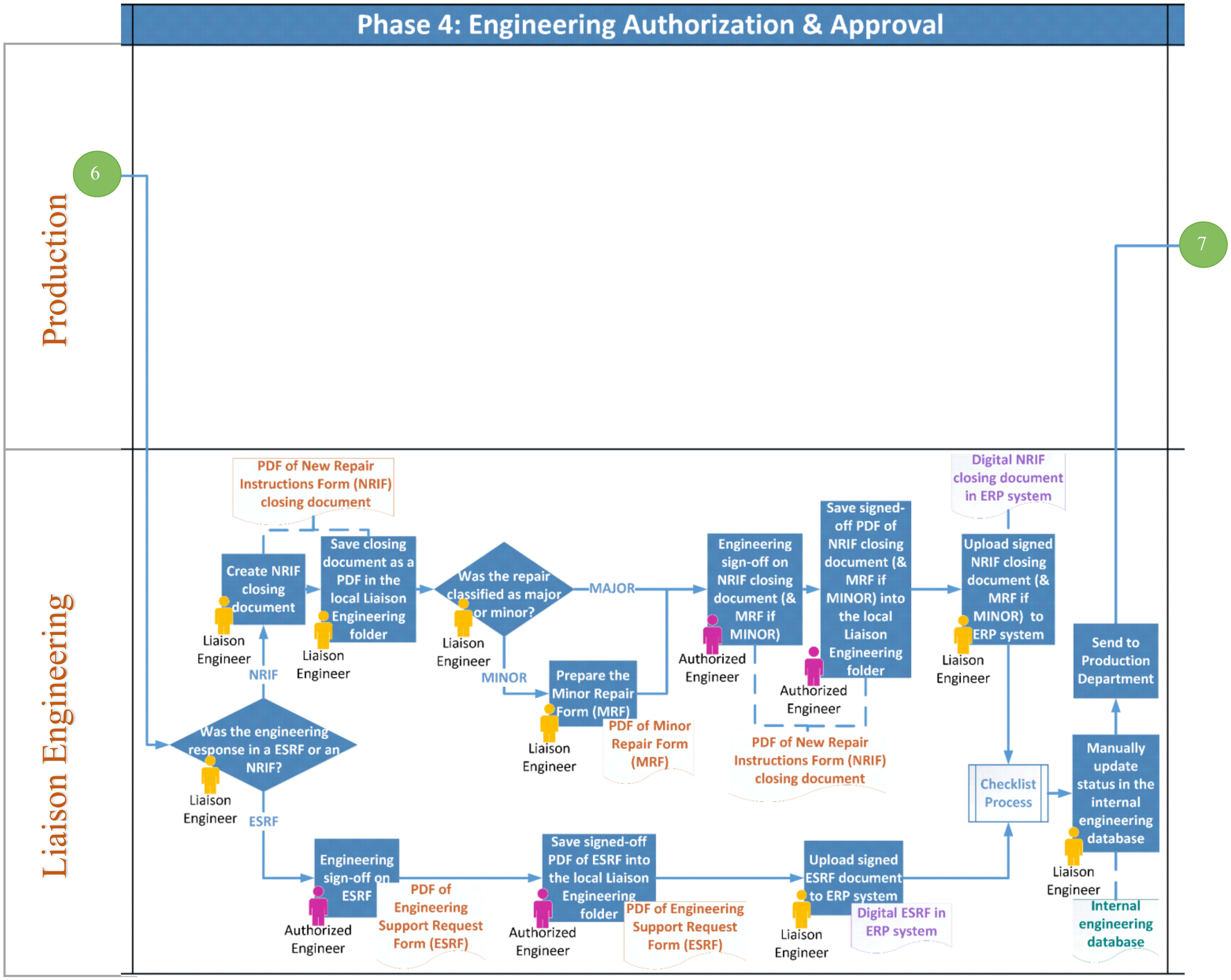

Figure A. 17: Phase 4 of the Level 3 process map.

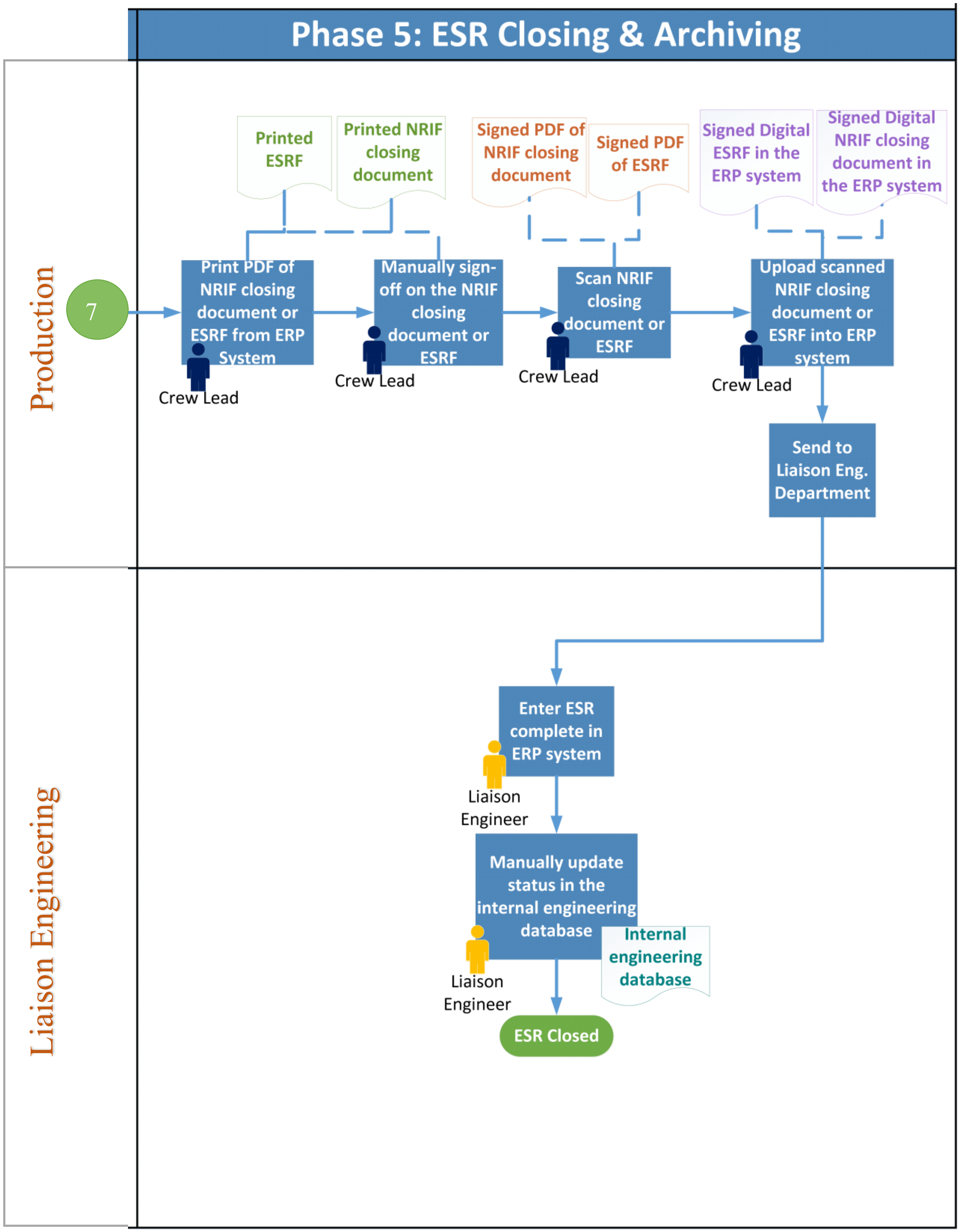

Figure A. 18: Phase 5 of the Level 3 process map.

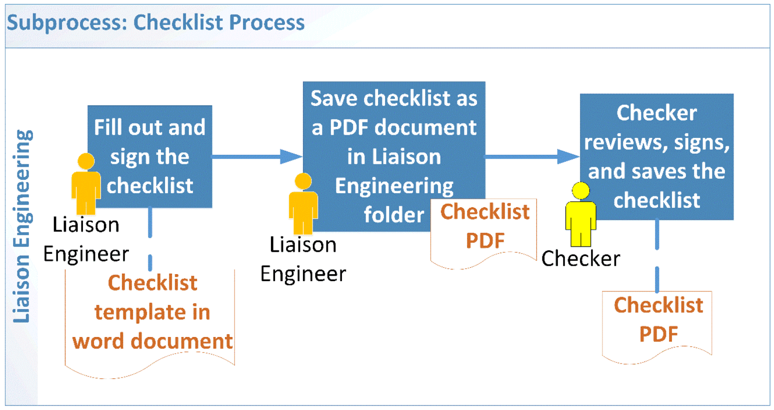

Figure A. 19: Subprocess “Checklist Process” in the Level 3 process map.

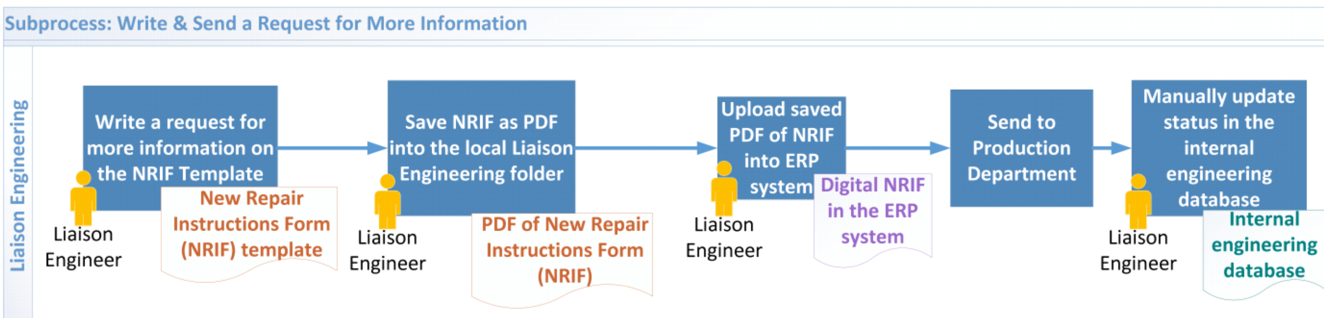

Figure A. 20: Subprocess "Write & Send a Request for More Information" in the Level 3 process map.

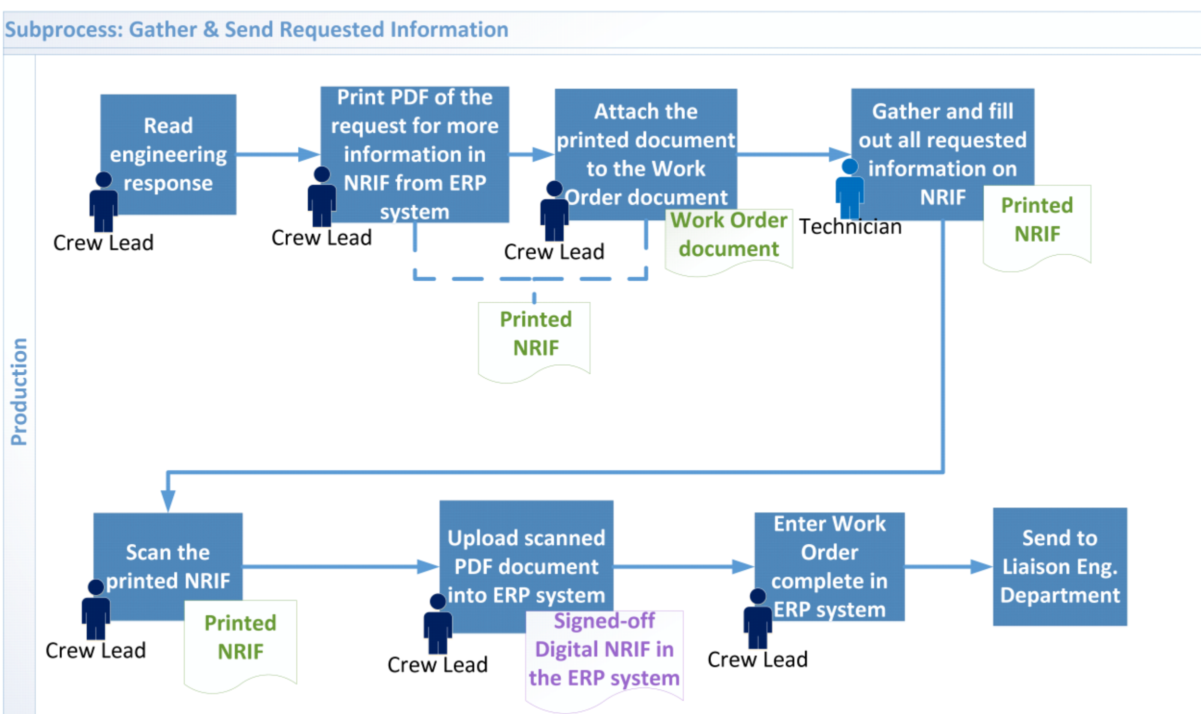

Figure A. 21: Subprocess “Gather & Send Requested Information” in the Level 3 process map.

Appendix G: Level 4 process map figures

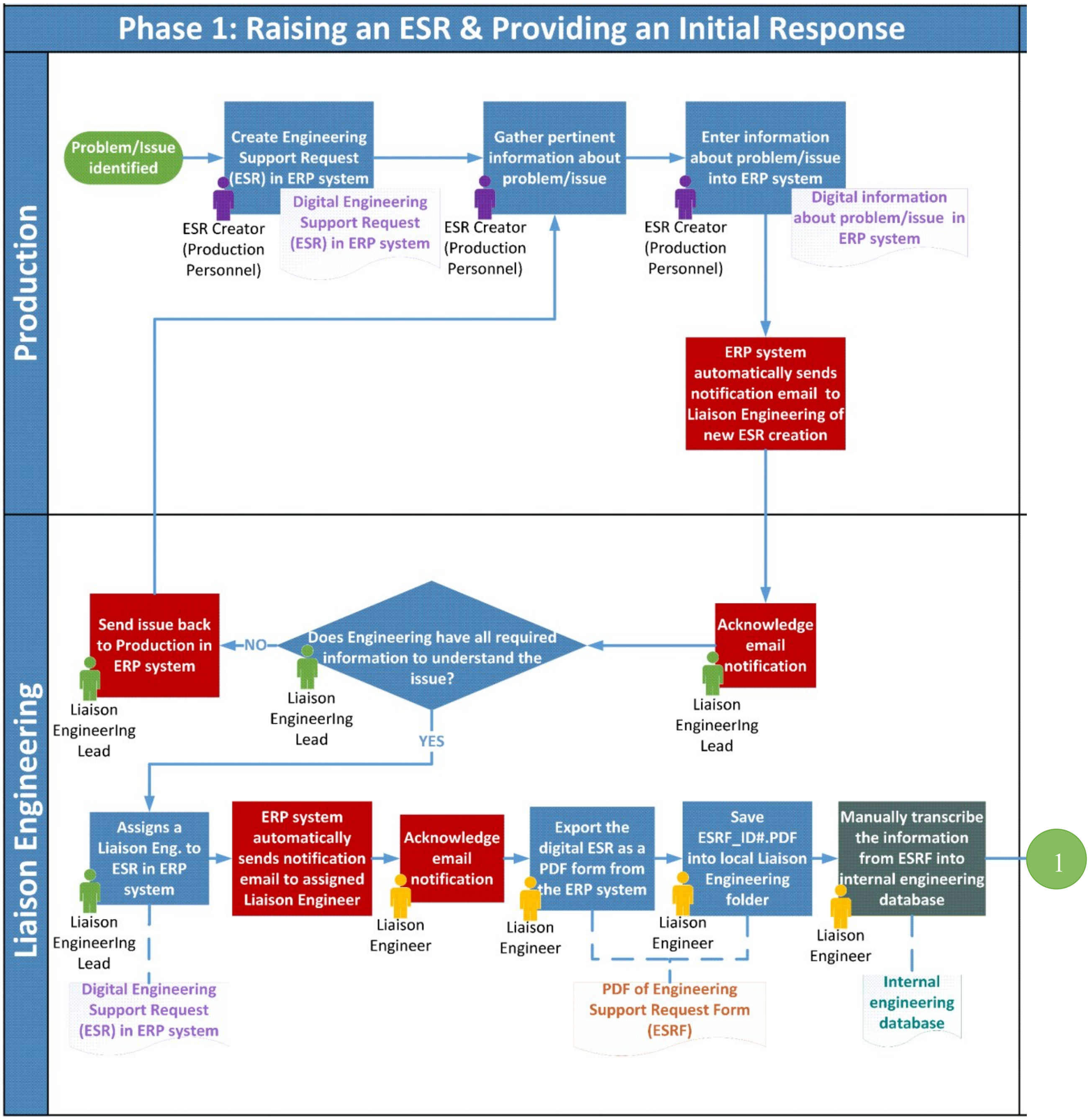

Figure A. 22: Phase 1 of the Level 4 process map.

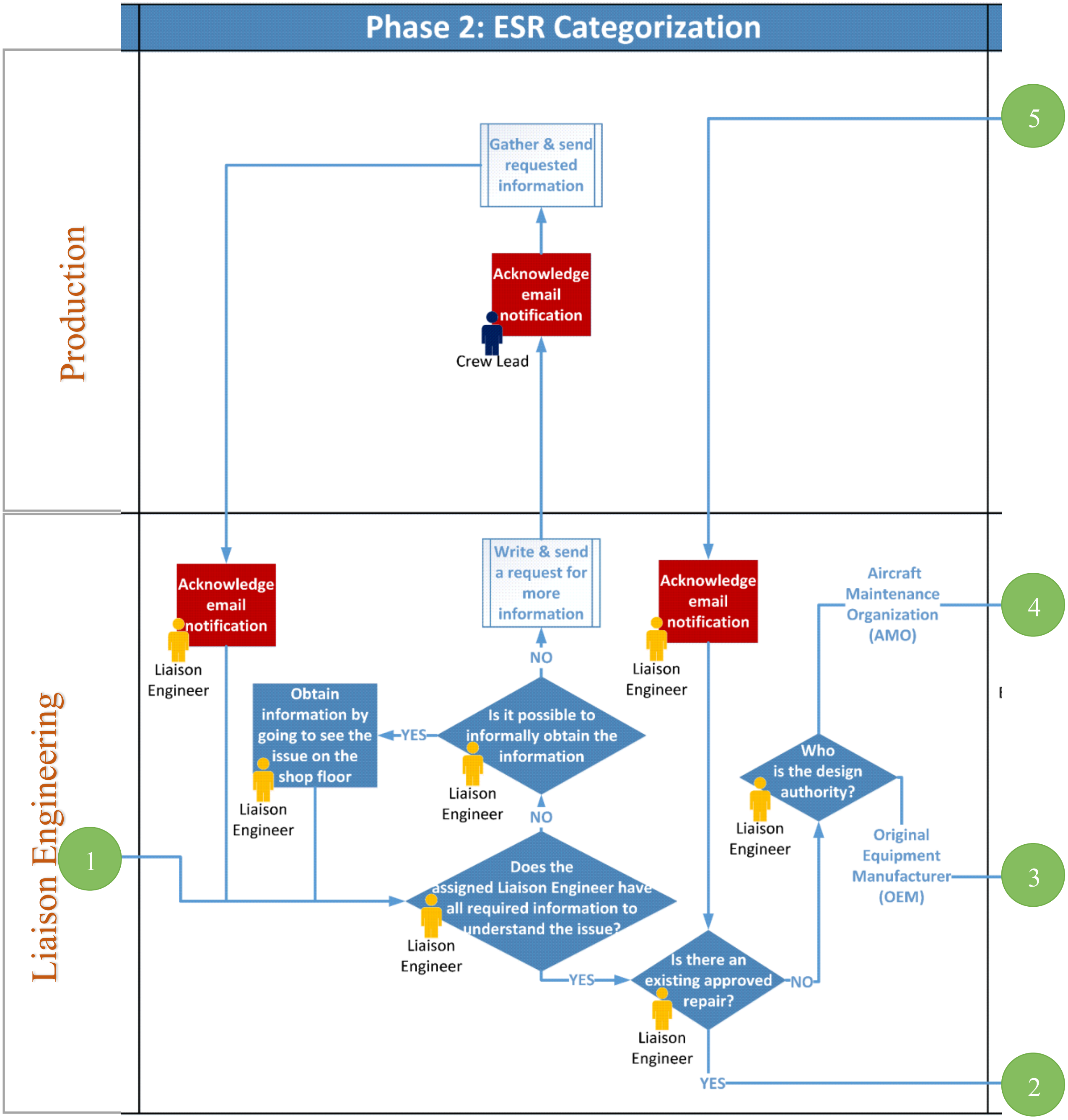

Figure A. 23: Phase 2 of the Level 4 process map.

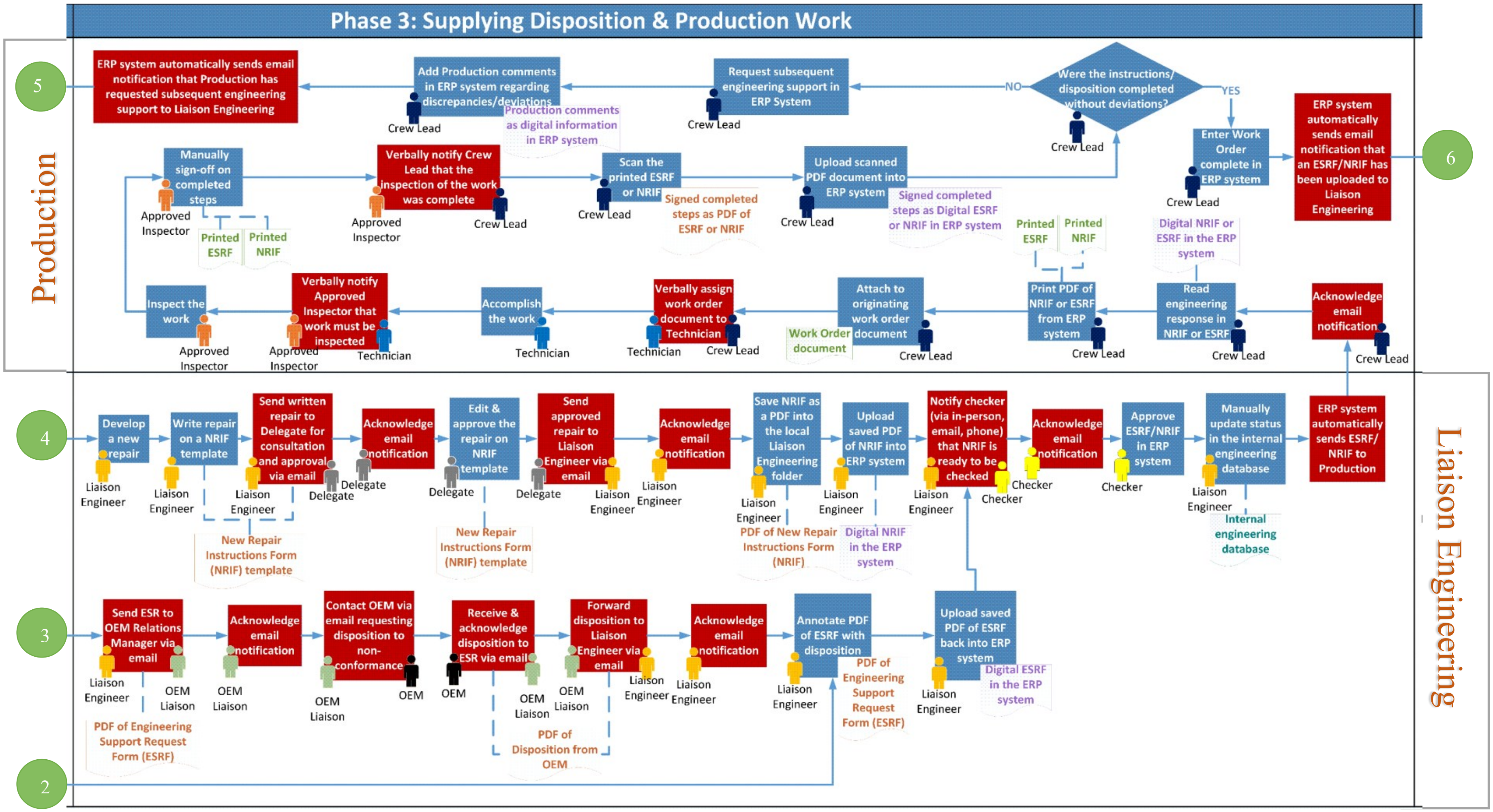

Figure A. 24: Phase 3 of the Level 4 process map.

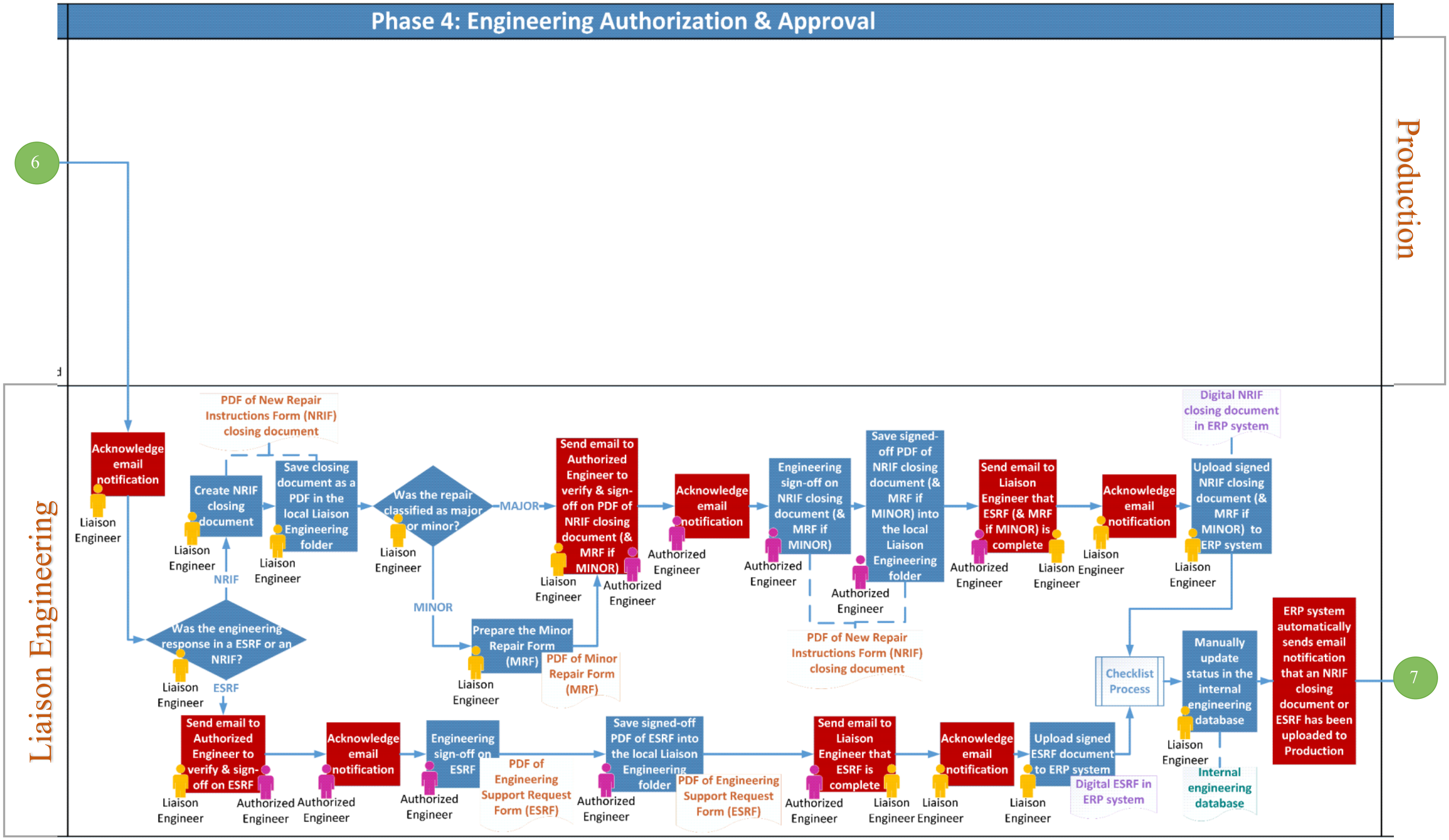

Figure A. 25: Phase 4 of the Level 4 process map.

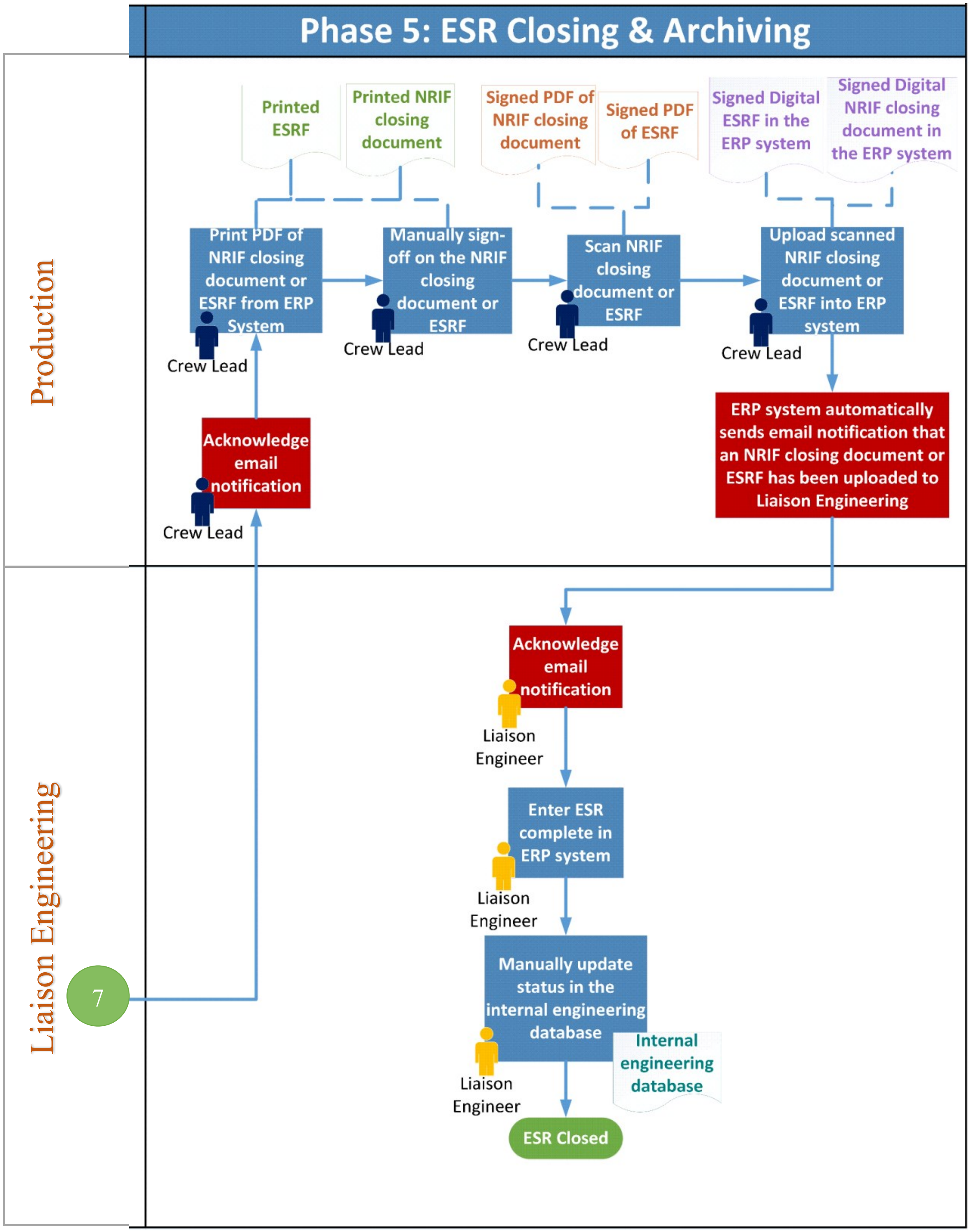

Figure A. 26: Phase 5 of the Level 4 process map.

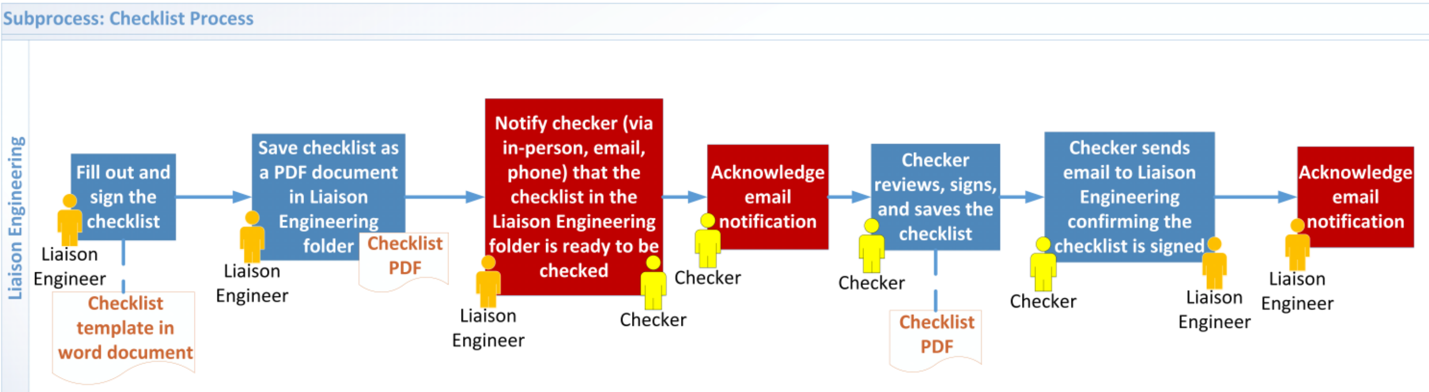

Figure A. 27: Subprocess “Checklist Process” in the Level 4 process map.

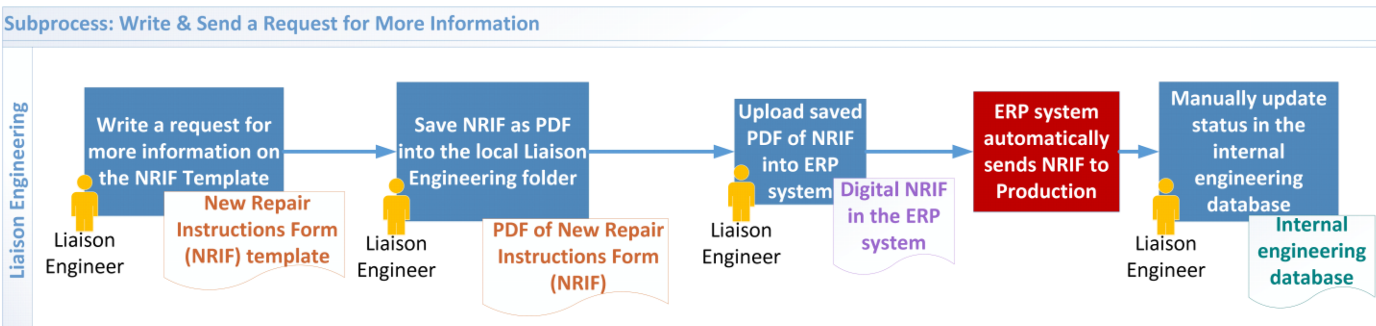

Figure A. 28: Subprocess "Write & Send a Request for More Information" in the Level 4 process map.

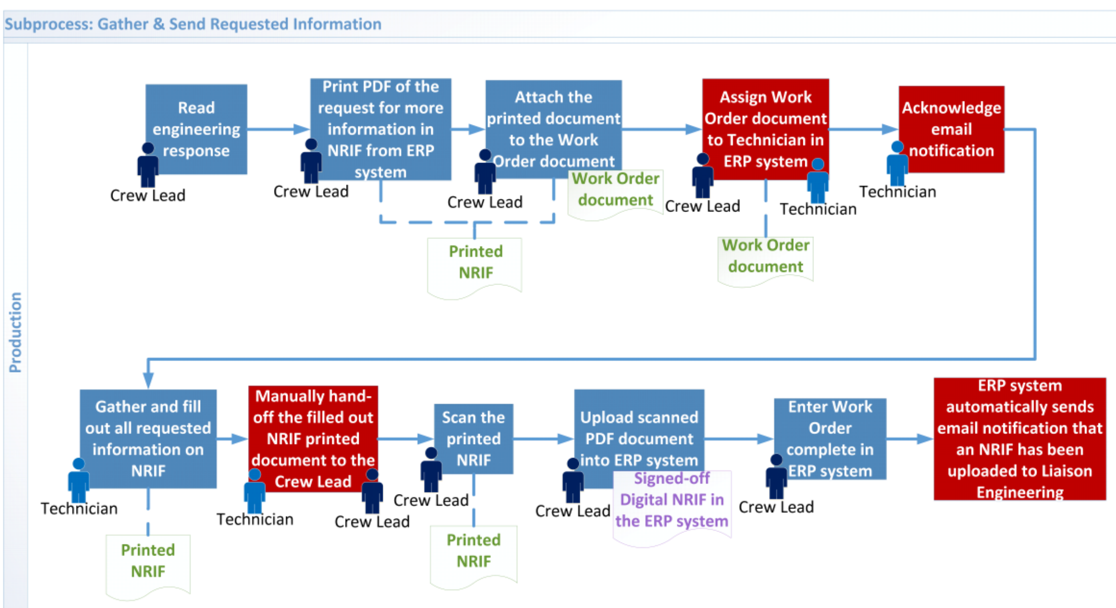

Figure A. 29: Subprocess “Gather & Send Requested Information” in the Level 4 process map.

Appendix H: Level 5 process map figures

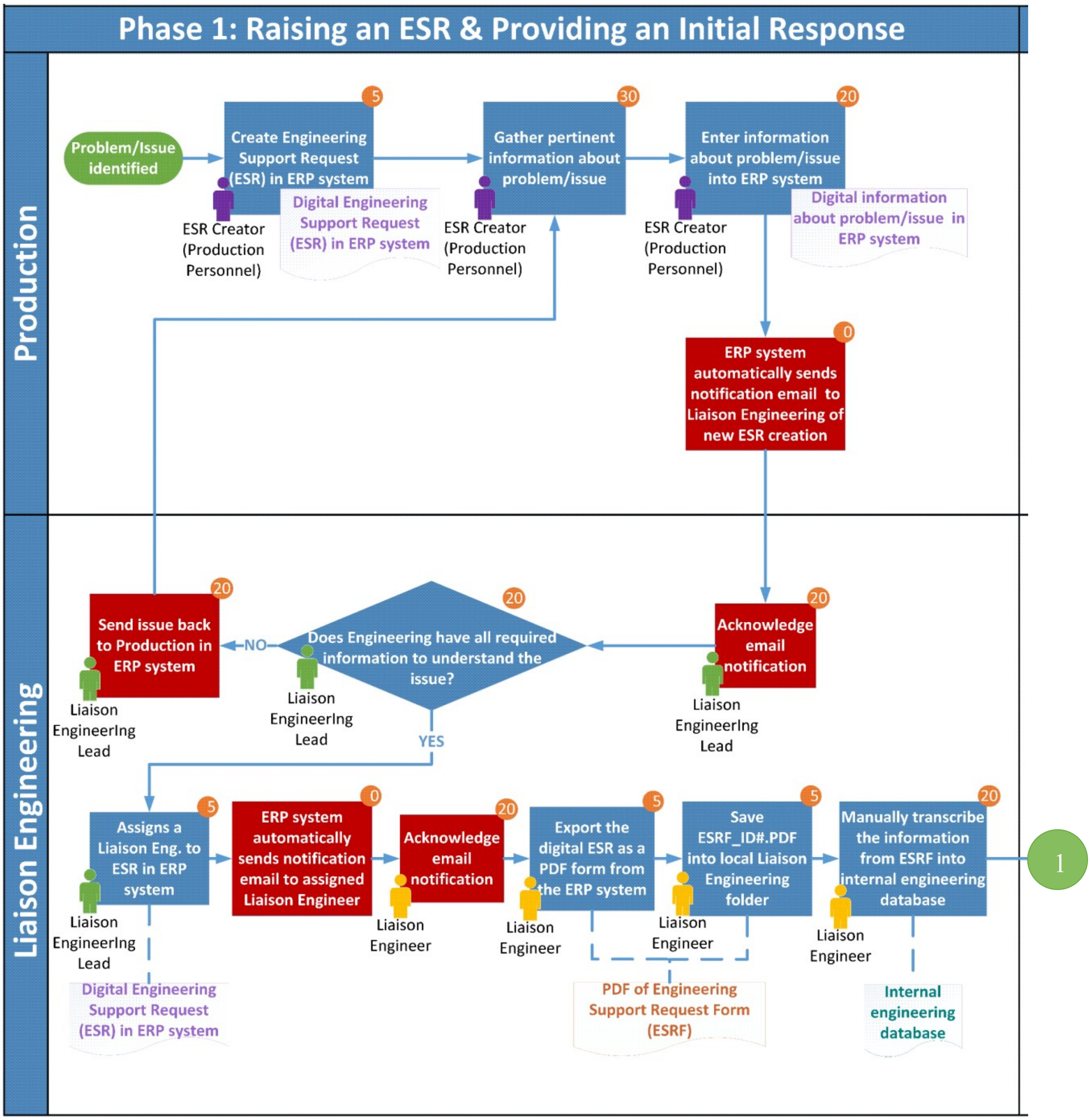

Figure A. 30: Phase 1 of the Level 5 process map.

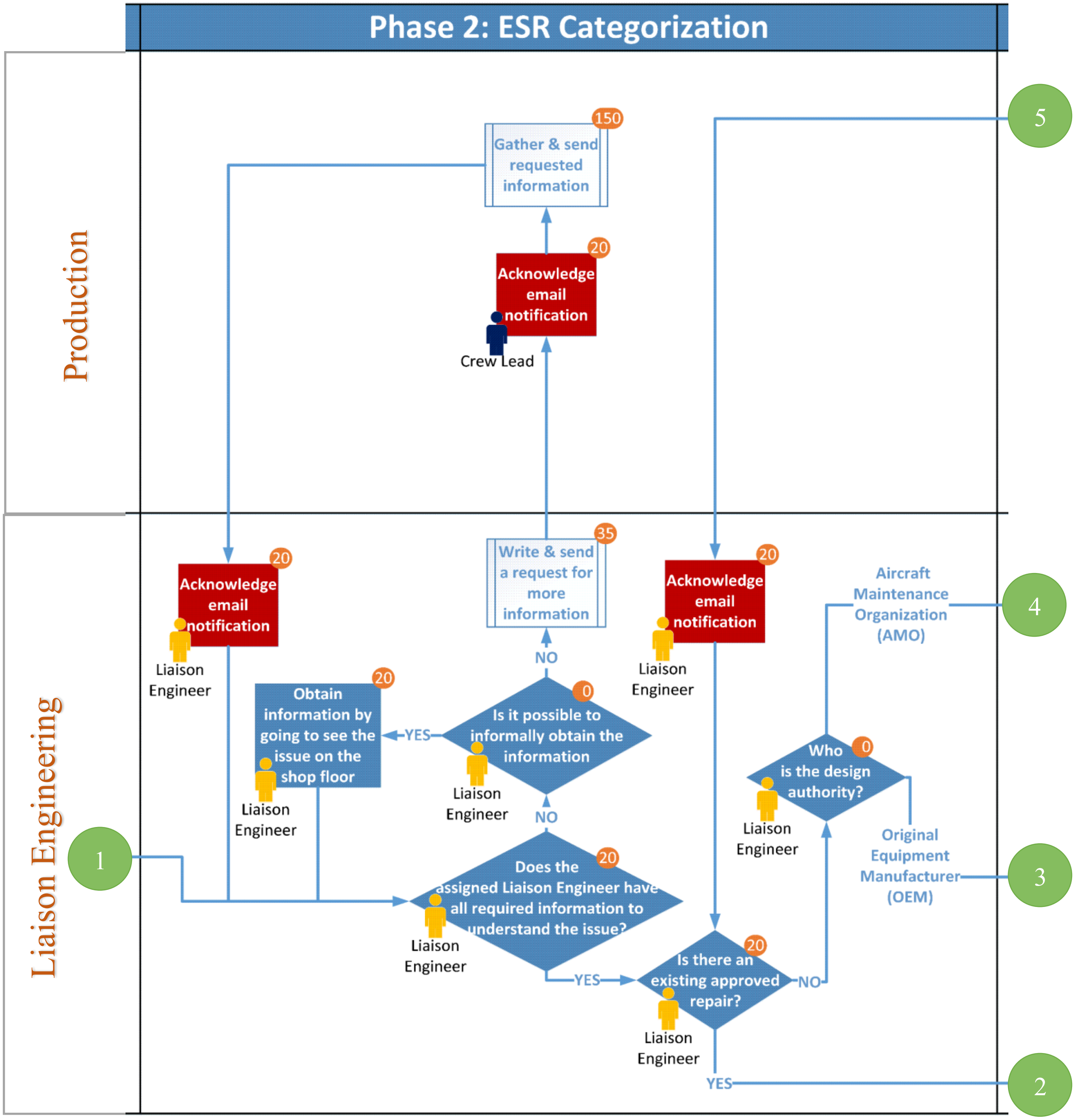

Figure A. 31: Phase 2 of the Level 5 process map.

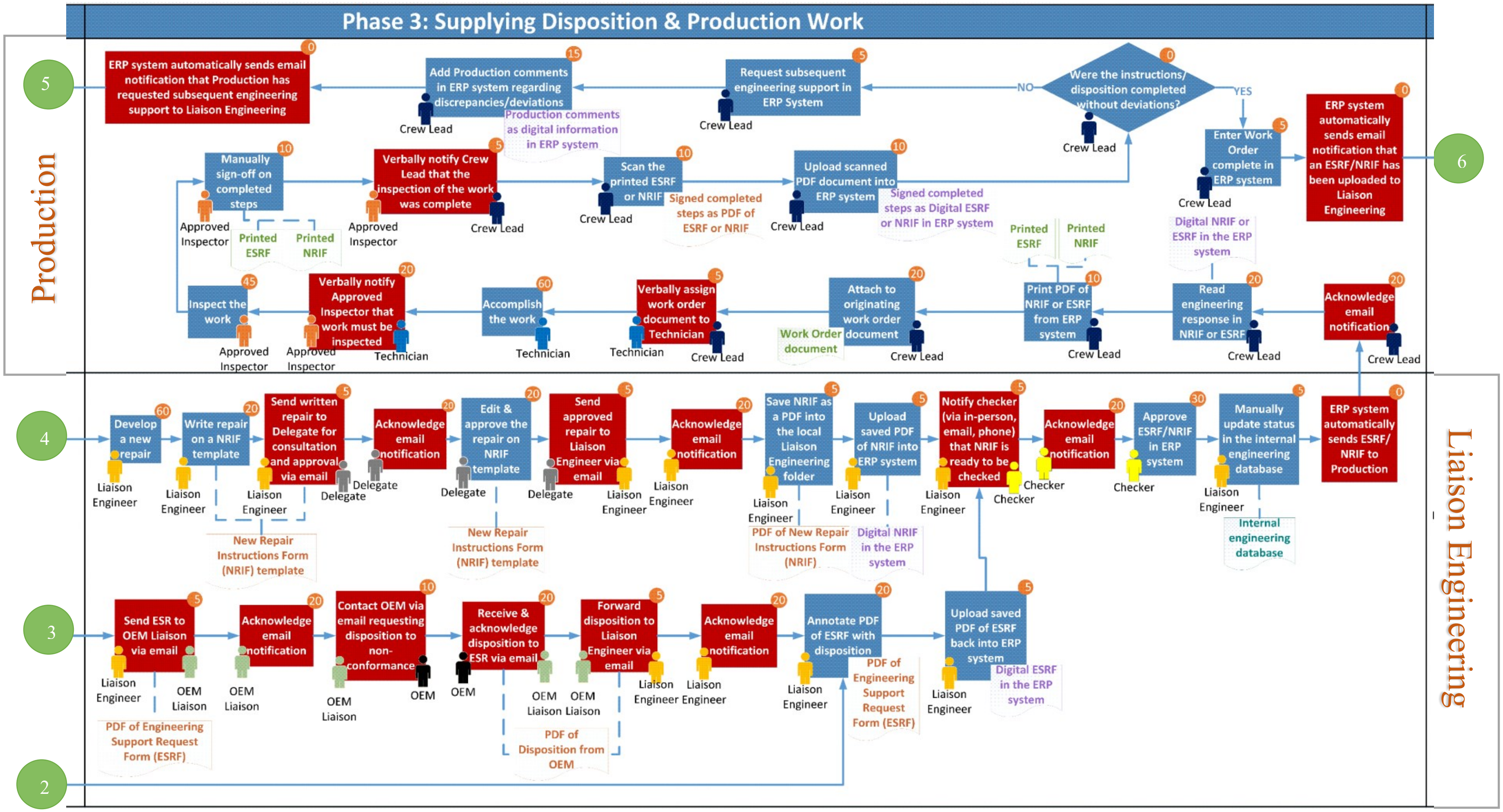

Figure A. 32: Phase 3 of Level 5 process map.

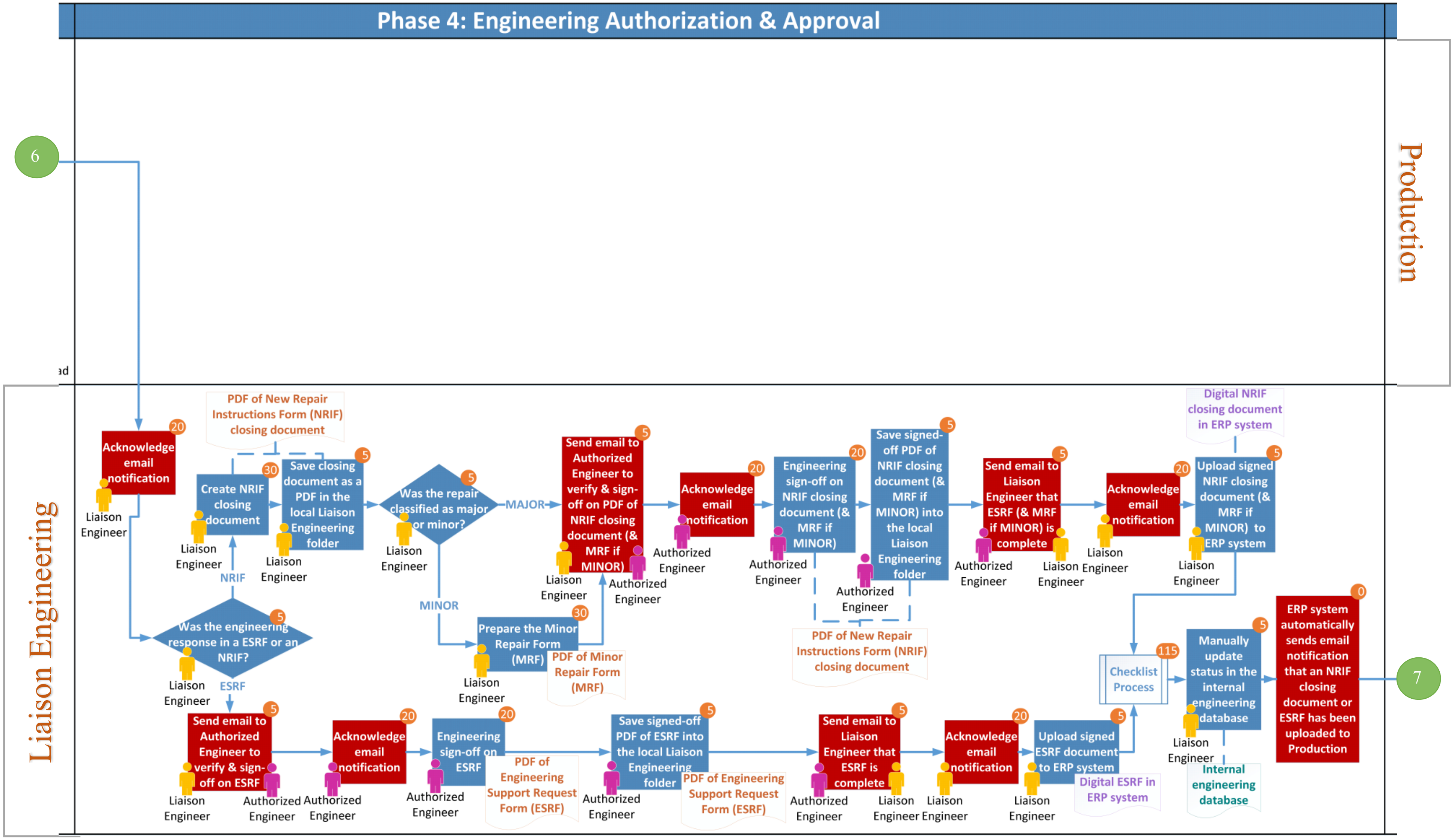

Figure A. 33: Phase 4 of the Level 5 process map.

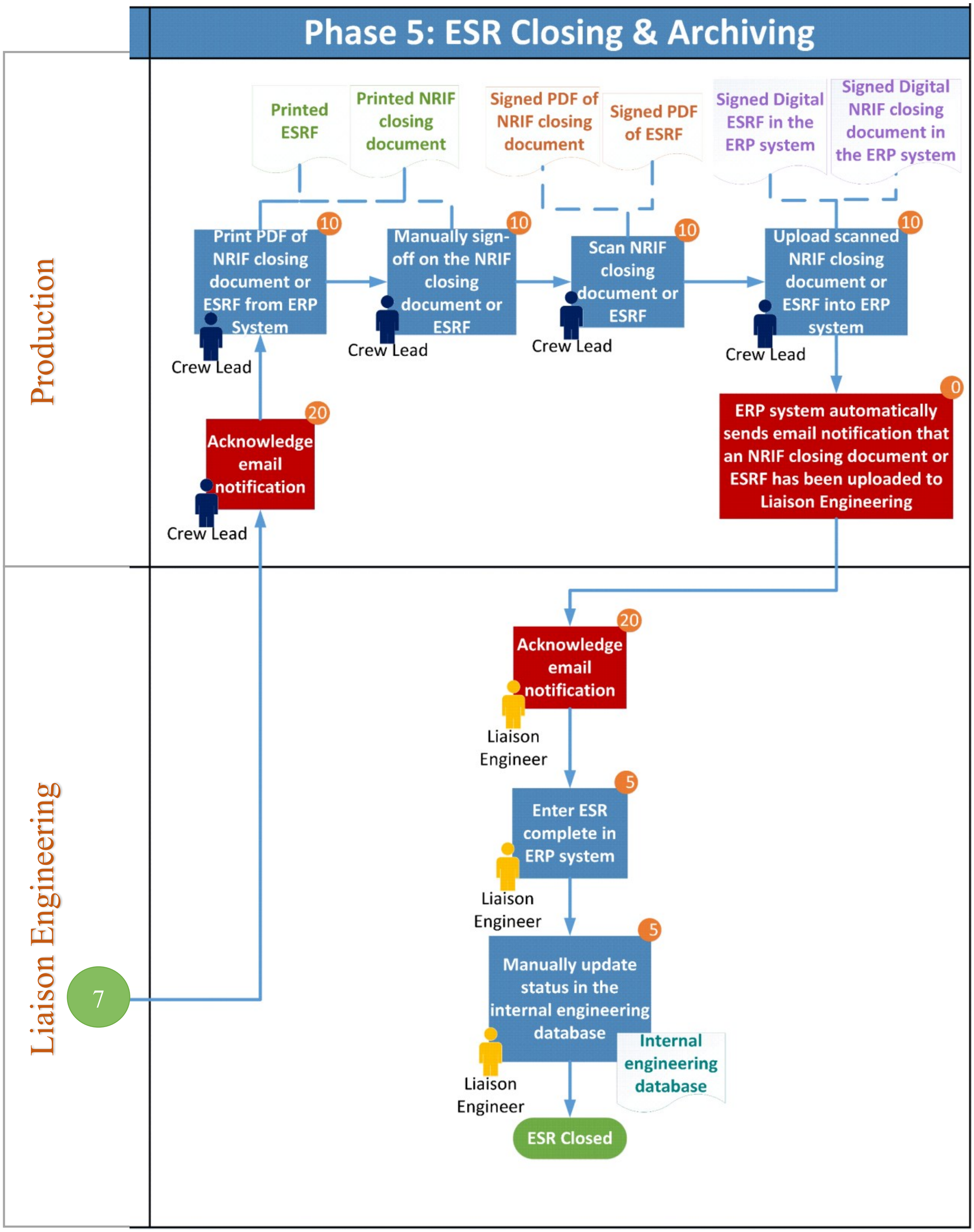

Figure A. 34: Phase 5 of the Level 5 process map.

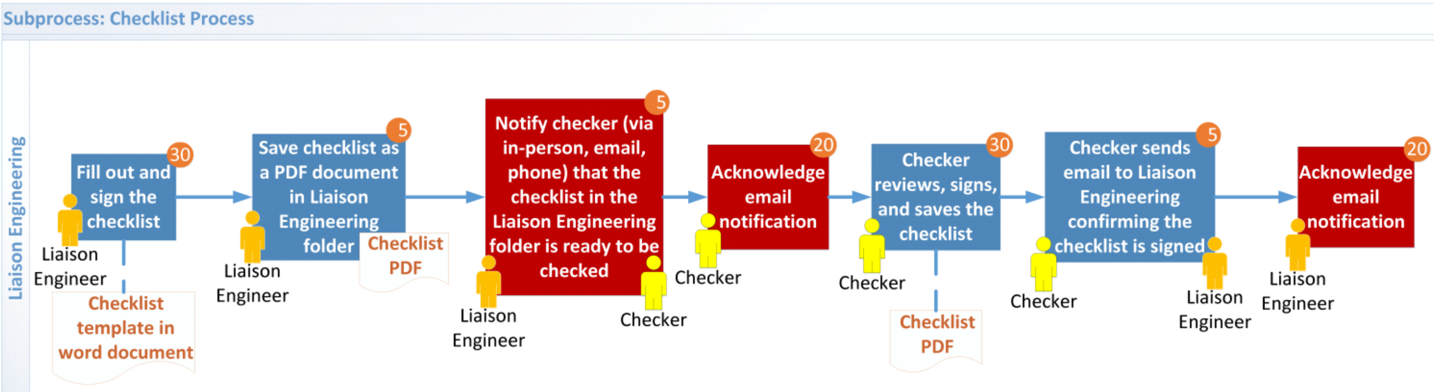

Figure A. 35: Subprocess “Checklist Process” in the Level 5 process map.

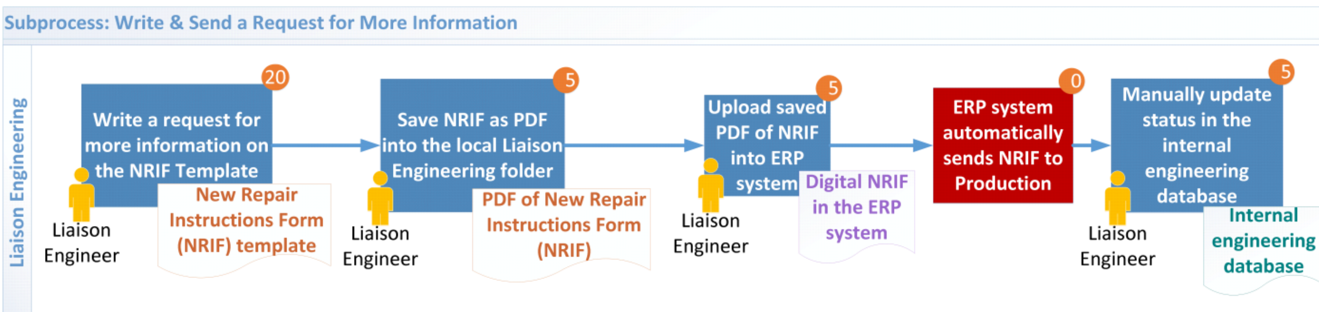

Figure A. 36: Subprocess "Write & Send a Request for More Information" in the Level 5 process map.

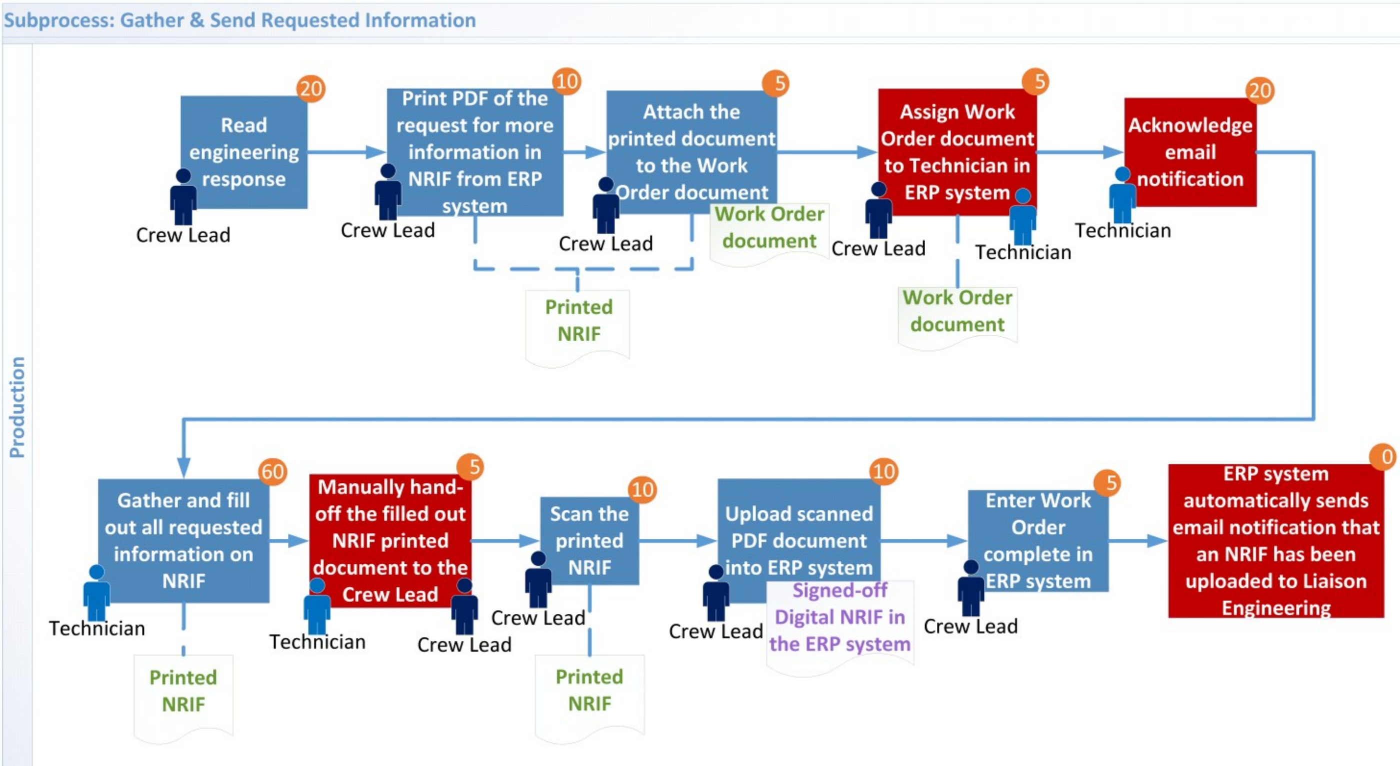

Figure A. 37: Subprocess "Gather & Send Requested Information" in the Level 5 process map.

Appendix I: Example of process path durations

Incorporating time into the process map enables the calculation of the approximate total working time required for various paths within the process. This involves summing up the durations of activities across each swimlane and phase. The resulting total times are presented in Table A. 1, displaying the sequential progression of the process across swimlanes and phases.

Table A. 1: Breakdown of total working time across process paths.

Phase	Swimlane	Total working time (minutes)
1	Production	Process: Raising an engineering support request (ESR): 55 minutes. Exception: If additional information is required by Liaison Engineering add 50 minutes per request for additional information.
1	Liaison Engineering	Process: Acknowledge, assign, and save the ESR: 95 minutes. Exception: If additional information is required by Liaison Engineering add 60 minutes per request for additional information.
2	Liaison Engineering	Process: Categorize the ESR Path 1: If there is an existing approved repair: 40 minutes Path 2: If there is no existing approved repair & the OEM is the designated design authority: 40 minutes. Path 3: If there is no existing approved repair & the AMO is the designated design authority: 40 minutes. Exceptions: 1. If additional information is required by Liaison Engineering add 40 to 75 minutes per request for additional information. 2. If Production encounters problems/issues with the instructions/disposition or if any deviations occur in Phase 3, add 20 minutes to the appropriate path (1, 2, or 3).
2	Production	Process: Gather and send requested information (only if Liaison Engineering is requesting more information in Phase 2): 170 minutes
3	Liaison Engineering	Process: Develop, document, and send engineering instructions/disposition Path 1: If there is an existing approved repair: 85 minutes. Path 2: If there is no existing approved repair & the OEM is the designated design authority: 165 minutes. Path 3: If there is no existing approved repair & the AMO is the designated design authority: 220 minutes.

3	Production	Process: Execute engineering instructions/disposition: 240 minutes Exceptions: If Production encounters problems/issues with the instructions/disposition or deviations occur add 20 minutes per request for additional assistance from Liaison Engineering.
4	Production	N/A
4	Liaison Engineering	Process: Check and approve instructions/disposition Path 1: If the previous engineering response was addressed in a New Repair Instructions Form (NRIF): 265 minutes. Path 2: If the previous engineering response was addressed in an Engineering Support Request Form (ESRF): 225 minutes. Exception: If the new repair was classified as "minor" add 30 minutes to Path 1 only.
5	Production	Process: Close an ESR: 60 minutes.
5	Liaison Engineering	Process: Close an ESR: 30 minutes