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Master Thesis

Proposal

Implementation of GenAI based Prototype for Systems Engineering Qualification Planning Tool

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1 Introduction

The modern engineering landscape is undergoing transformation as traditional mechanical and electrical systems evolve into cyber-physical systems characterized by dynamic networking, autonomy, and sociotechnical integration [DAG+21]. This paradigm shift has altered product development, introducing exponential increases in system interfaces, heightened requirements for interdisciplinary collaboration, and accelerated development cycles coupled with elevated quality and flexibility demands [WSK+21]. Organizations across industries now face the challenge of developing complex, interconnected systems that integrate hardware, software, and services while managing increasingly diverse stakeholder requirements and shorter time-to-market pressures.

Systems Engineering (SE) has emerged as the essential methodology for mastering this growing complexity and orchestrating effective interdisciplinary development processes [INC22]. SE provides a transdisciplinary and integrative approach that enables successful realization, use, and retirement of engineered systems through systematic application of engineering principles, scientific methods, and management practices [INC22]. The methodology's proven ability to manage complex system development has made it indispensable for industries, where successful SE implementation directly correlates with improved project outcomes and reduced development risks.

Despite these recognized benefits, the introduction and company-wide implementation of SE remains a challenge for most organizations. Companies struggle to establish uniform SE approaches due to varying organizational maturity levels, diverse role profiles, and heterogeneous employee competencies that create barriers to systematic adoption [WGB+23]. To address this challenge, this research develops a Systems Engineering Qualification Planning Tool (SE-QPT) prototype that provides systematic, maturity-based approaches to SE qualification planning.

This research follows the Design Science Research Methodology (DSRM) framework [PTR+07], progressing through six systematic phases: problem identification, solution objectives definition, design and development, demonstration, evaluation, and communication. This proposal establishes the methodological foundation by addressing problem identification and motivation (Chapters 1-2) and defining solution objectives (Chapters 3-4), with subsequent thesis work focusing on design, demonstration, and evaluation of the SE-QPT prototype.

2 Problem Identification and Research Objectives

This chapter provides a comprehensive analysis of the challenges organizations face with respect to SE implementation and utilization. Following the DSRM approach established in Chapter 1, this analysis systematically identifies and examines the specific problems that necessitate the development of an intelligent qualification planning solution.

The absence of systematic, company-specific qualification planning represents a critical gap that hinders effective SE adoption and utilization. While existing research has established frameworks for maturity assessment and competency evaluation in SE contexts, current approaches often address individual components in isolation—such as competency assessment, learning format selection, or maturity evaluation — without providing unified platforms that enable holistic, data-driven qualification planning ***(O5)*** [WWK22][Kum23]. This fragmented approach limits organizations' ability to develop coherent, evidence-based strategies for building SE capabilities across their workforce.

Contemporary organizations face unprecedented challenges as SE implementation becomes crucial for managing increasing product complexity and interdisciplinary development requirements [WGB+23]. Research conducted through the SE4OWL project reveals that SE introduction represents a demanding transformation process for companies, with empirical studies involving 78 hypotheses from 13 expert interviews and validation through 112 survey participants demonstrating that 40 out of 52 validated hypotheses confirm significant implementation barriers across multiple organizational dimensions [WGB+23].

The analysis reveals five critical problem areas that necessitate integrated solution approaches: organizational structure transformation, employee qualification gaps ***(O2, O6)***, motivational barriers, limiting general conditions, and inadequate introduction methods [WGB+23][WSK+21]. Employee qualification emerges as a fundamental challenge, with most employees lacking the expertise required for SE implementation, while the importance of qualification has increased significantly in recent years. Companies struggle with systematic qualification planning that can bridge the gap between generic SE competency frameworks and specific organizational contexts ***(O1, O3)***.

The need for Generative AI integration emerges from the scale and complexity of qualification planning requirements in SE contexts. Companies implementing SE face the challenge of generating and managing large numbers of company-specific learning objectives ***(O3)*** that must align with organizational processes, methods, tools, and individual role

requirements while maintaining consistency with established SE standards [KWA+22]. Traditional manual approaches cannot effectively handle the complexity of mapping diverse organizational roles to standardized competency frameworks ***(O2)*** and generating contextually appropriate learning objectives for multiple stakeholder groups ***(O3, O6)*** [Kum23].

Retrieval-Augmented Generation (RAG) technology offers capabilities for generating company-specific learning objectives ***(O3)*** by combining the contextual understanding of large language models with systematic retrieval from validated SE competency frameworks [GXG+23]. This technological approach addresses the fundamental scalability challenges in qualification planning while ensuring alignment with established SE principles and standards [LPP+21]. The challenge of selecting appropriate learning formats ***(O4)*** and creating personalized learning paths ***(O6)*** further compounds the complexity of systematic qualification planning.

2.1 Objectives

Based on this comprehensive problem analysis, the research objectives for developing a prototype for an AI-enhanced Systems Engineering Qualification Planning Tool (SE-QPT) are defined as follows:

O1. Maturity-Based Assessment Integration: Develop systematic organizational maturity assessment capabilities that evaluate SE processes, methods, and tools to enable maturity-specific qualification strategies, building upon established frameworks [WPH+22] while incorporating decision trees for systematic qualification archetype selection.

O2. AI-Enhanced Competency Assessment: Integrate Roby's [Rob25] Competency Assessor with it's role mapping algorithms that can systematically map unknown organizational roles to established role clusters [KWA+22].

O3. RAG-Based Learning Objective Generation: Implement Retrieval-Augmented Generation capabilities [LPP+21] that generate company-specific learning objectives from standardized templates, incorporating organizational context, PMT configurations, and competency gaps while ensuring consistency with SE principles [MWA+23].

O4. Learning Format Selection: Develop systematic learning format selection mechanisms that consider organizational characteristics, participant numbers, and qualification objectives [Kum23], enhanced by personalization approaches [SS20] to optimize training effectiveness based on archetype requirements.

O5. Integrated Platform Development: Create a comprehensive web-based qualification planning platform that integrates all methodology components, providing intuitive interfaces for organizational administrators and employees while implementing modular design principles for future enhancement and customization capabilities.

O6. Learning-Module-Planning: Develop module selection and sequencing capabilities that create cohort-based training programs with individual customization options. The system will cluster employees with similar competency patterns and role requirements into training cohorts, design core group curricula for efficient delivery, while enabling personalized learning paths through additional individual modules, flexible pacing, and customized depth based on specific competency gaps and learning preferences.

The primary objective of this thesis is to develop a prototype of Systems Engineering Qualification Planning tool (SE-QPT) that integrates maturity-level specific qualification planning methodologies with competency assessment capabilities [KWA+22][WWK22]. This tool will enable organizations to systematically plan and implement their SE qualification strategies based on their specific maturity levels, role configurations, and competency requirements.

The SE-QPT aims to bridge the gap between theoretical SE frameworks and practical organizational implementation by providing an intelligent, adaptive platform that can generate company-specific learning objectives, map diverse organizational roles to standardized competency frameworks, and recommend optimal qualification strategies and learning formats based on organizational characteristics.

3 Solution Idea

3.1 Overview

The proposed Systems Engineering Qualification Planning Tool (SE-QPT) addresses the challenge of introducing and scaling Systems Engineering (SE) capabilities within organizations by providing a systematic, maturity-based approach to qualification planning [WPH+22]. Drawing from the established methodology by Niemeyer [Nie25], this tool integrates various assessment and planning frameworks to deliver company-specific learning strategies that align with organizational maturity levels and individual competency gaps.

3.2 Core Solution Architecture

The SE-QPT solution is structured around a comprehensive four-phase methodology that transforms company inputs regarding Processes, Methods, and Tools (PMT) into actionable qualification strategies through an integrated RAG-LLM system. The core technical innovation leverages Retrieval-Augmented Generation (RAG) technology [LPP+21] with Large Language Models to transform standardized SE learning objectives into company-specific formulations, addressing the challenge of bridging generic competency frameworks with specific organizational contexts.

3.2.1 Phase 1: Prepare SE Training - Organizational Assessment and Strategy Selection

Objective: Establish the foundation for SE training by assessing organizational readiness and selecting appropriate training strategies.

Key Activities:

- **Determine Current Maturity Level (Maturity Model)**: Implement comprehensive organizational assessment through established SE maturity models that evaluate existing processes and roles across multiple organizational dimensions [WPH+22]. The maturity assessment framework provides objective baseline measurements of organizational SE capabilities across processes, methods, and tools dimensions.
- **Identify SE Roles (Role Clusters)**: Systematic mapping of existing company roles to standardized Role Clusters using KÖNEMANN et al.'s [KWA+22] role clustering approach, enhanced by Derik's [Rob25] Competency Assessor. This enables

clear assignment of employees to one or more role clusters based on responsibilities and competency requirements.

- **Select SE Training Strategy (Decision Tree, Strategy Profiles)**: Utilize structured decision tree architecture that guides qualification strategy selection based on organizational maturity, implementing systematic archetype identification mechanisms [Nie25]. The system applies validated qualification archetypes that reflect different organizational contexts and strategic approaches.

Deliverables: SE Maturity Level, SE Roles, and SE Training Strategy.

3.2.2 Phase 2: Determine Requirements and Competencies - Gap Analysis and Learning Objective Generation

Objective: Identify specific competency gaps and formulate targeted learning objectives based on role requirements and organizational context.

Key Activities:

- **Determine Necessary Competencies (SE Competencies, Process-Competency-Matrix)**: Integrate Derik Roby's [Rob25] Competency Assessor methodology to evaluate current competency levels against target requirements for each identified role cluster using validated methodologies for systematic evaluation.
- **Formulate Learning Objectives (Learning Objective Templates)**: The core RAG-LLM innovation generates Company-specific Learning Objectives by transforming standardized learning objective templates into contextually relevant goals that reflect the organization's specific PMT environment and strategic objectives.
- **Identify Competency Gaps (Competency Assessor)**: Systematic comparison between current competency levels and target requirements to identify specific areas requiring training intervention, utilizing AI-driven competency assessment approaches.

Deliverables: Competency Gaps and Learning Objectives.

3.2.3 Phase 3: Macro-planning of SE Training Initiative - Module Selection and Format Optimization

Objective: Design the overall training program structure by selecting appropriate modules and learning formats for cohort-based delivery.

Key Activities:

- **Define Modules**: Select appropriate competence modules from a comprehensive library of SE competence modules that align with the INCOSE framework extended by KÖNEMANN et al. [KWA+22]. The tool employs a modular approach to competence development.
- **Select Formats (Qualification Format Profiles, Decision Tree)**: Learning format selection represents a matching process that considers multiple organizational parameters. Drawing from Kumar's learning format profiles [Kum23], the system recommends appropriate delivery methods based on company size, participant numbers, competency targets, and preferred learning approaches.

Deliverables: SE Training Macro-concept.

3.2.4 Phase 4: Micro-planning of SE Training Initiative - Implementation Planning and Individual Customization

Objective: Create detailed implementation plans with individual learning paths within cohort frameworks.

Key Activities:

- **Define Detailed Concept(Concept Templates)**: Translate strategic frameworks into concrete implementation plans utilizing systematic approaches that consider both technical and organizational factors [Pan23]. This includes creating cohort-based training programs with individual customization options, clustering employees with similar competency patterns into training cohorts while enabling personalized learning paths.

Deliverables: SE Training Detailed Concept.

4 Preliminary Structuring

1. Introduction
    - 1.1 Background and Motivation
    - 1.2 Problem Definition
    - 1.3 Research Objectives
    - 1.4 Thesis Structure
2. Literature Review
    - 2.1 Systems Engineering Qualification Frameworks
    - 2.2 Qualification Planning Methodologies
    - 2.3 Learning Format Selection and Implementation
    - 2.4 AI-Driven Approaches
3. Methodology and System Design
    - 3.1 Research Design and Approach
    - 3.2 SE-QPT System Architecture
    - 3.3 Maturity Assessment and Decision Tree Implementation
    - 3.4 Competency Assessment Integration
    - 3.5 RAG-LLM Implementation for Learning Objective Customization
    - 3.6 Learning Format Selection
4. Solution Implementation
    - 4.1 SE-QPT Platform Development
    - 4.2 AI System Implementation
    - 4.3 Assessment and Mapping Algorithms
    - 4.4 Learning Format Recommendation Engine
    - 4.5 System Testing
5. Validation and Evaluation
6. Results and Analysis
7. Conclusion and future work

5 Time Plan

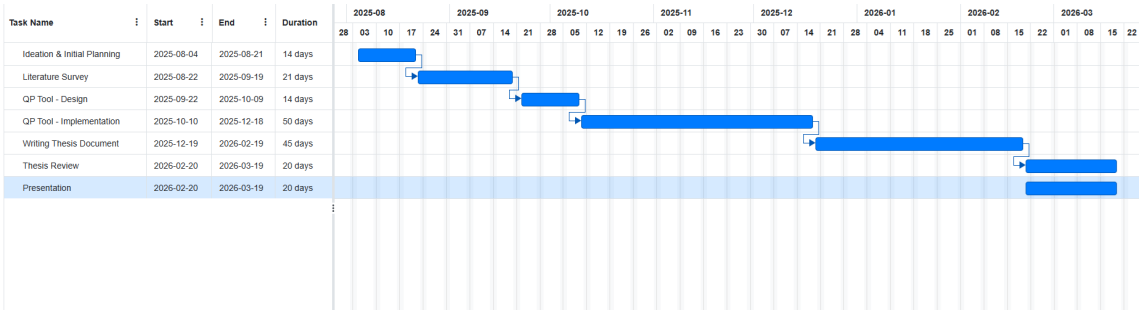

Figure 5-1: Time Plan

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