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Compare and Analysis MBSE Benefits with Document-Centric Traditional System Engineering Approach

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Abstract

According to the literature study, there is limited information that compares their MBSE method to a document-centric strategy, employing metrics to give quantitative evidence of the advantages of MBSE techniques over traditional, document-based approaches. This research aims to analyze this issue using a real-world example that many can easily relate to. This paper presents the ongoing research project. This research evaluates the traditional system engineering approach to estimate the throughput of a scaled-down serial flow line with unreliable machines and moderate buffers. The paper shows how a document-centric approach is used and how the stakeholders access documents to make changes that arise during the execution of the project. In this paper, we have identified a set of KPIs to compare the MBSE approach with the "document-centric" approach. This paper will concentrate on the use of a "document-centric" approach to solve the same problem and report performance based on the same set of KPIs as in the previous paper (Banik P, Sengupta S 2024).

Keywords
Model-based System Engineering, Model-based approach, Document-Centric, System engineering, MBSE Benefits, non-MBSE, traditional system engineering, TSE

1. Introduction
The Methodology of Traditional Systems Engineering (TSE) is a document-based technique to manage systems specification, requirements, design, verification, validation, and process information in different documents such as system descriptions, process flow diagrams, analyses, reports, etc. This Document-centric approach necessitates significant manual effort to manage system complexity while also maintaining traceability and uniformity throughout different phases of the product life cycle. It also conducted experiments to study the challenges of a document-centric strategy and the process complexity for a number of industrial use cases. The restrictions of traditional system engineering (TSE) usually result in inefficiencies, inconsistencies, and errors throughout the system development process. Furthermore, TSE can be an expensive and time-consuming process, which might hinder the effectiveness of designing complex systems. In this paper, we captured the entire process of a document-centric approach by analyzing the performance KPIs of a serial production line. The remainder of this paper follows this structure. The objectives and literature reviews are presented in the next section. The methodology and results of the analysis are followed by a discussion of insights in the subsequent section. The last section is dedicated to summarizing the conclusions and future research of the work presented in this paper.

1.1 Objectives

The objective is to provide evidence to establish that the document-centric approach offers a manual and semi-automatic approach to solving a system engineering problem. The current research aims to identify the system improvement measures, or KPIs, that can estimate the throughput rate of the three machines and two buffers in the serial production line system. Formulate the System model following the principles of the traditional system engineering concept and provide the recommended method that meets the system's key performance indicators while considering some assumptions.

2. Literature Review

We limited our keywords to "Model-Based Systems Engineering" OR "MBSE," "document-centric" OR "DBSE," and "Traditional System Engineering" to conduct an extensive search for related papers that had addressed the comparison of MBSE and document-centric methods in the context of system engineering. We set these keywords and kept them constant throughout the paper selection process. We performed the search using keywords that we entered into the database's search function, without any restrictions on where in the paper they could appear. The literature review led to the selection of model-based systems engineering and traditional system engineering areas for analysis. These areas were selected based on the comparative analysis of model-based and traditional systems engineering approaches, which was as described in the reference paper (Younse, Cameron and Bradley 2022).

According to the current literature review, only two papers substantiated their claims about comparing MBSE and document-centric approaches with empirical evidence and MBSE benefits. The first paper talked about a case study that contrasts an MBSE approach with a document-centric approach for modeling and simulating the architecture of a robotic space system. It also gave numbers that show MBSE is better than traditional system engineering approaches for modeling and simulating architecture (Younse, Cameron, and Bradley 2022). The second paper talked about the pros and cons of MBSE versus document-based systems engineering (DBSE). It also compared the two methods in a real system development project during the requirements definition phase and related design tasks (Maurandy, Helm, Gill, and Stalford 2012).The following are the key points from the literature review and reference papers (Younse, Cameron, and Bradle 2022, and Maurandy, Helm, Gill, and Stalford 2012). Future research papers should tackle these issues. Recommendations are made for future work especially comparing MBSE and

Traditional document-centric approach.

(1) If some of the document-centric approaches can be measured since measurability is a necessary condition for gathering empirical evidence, and
(2) If some benefits are obvious, then there is no need to formally measure them.
The current case study focused on comparing benefits, which are measured using a defined measurement methodology, and applied similar methods to evaluate the benefits for a comparative analysis between the MBSE and document-centric approach.

3. Methodology

The Document-Centric approach relies heavily on written documents to represent system requirements, designs, and other engineering artifacts. Here's an overview of the Document-Centric approach. To develop a model of a serial transfer line with three machines and two buffers using a Discrete Event Simulation (DES) approach in a document-centric (non-MBSE) methodology, follow these detailed steps (Law and Kelton 2000)

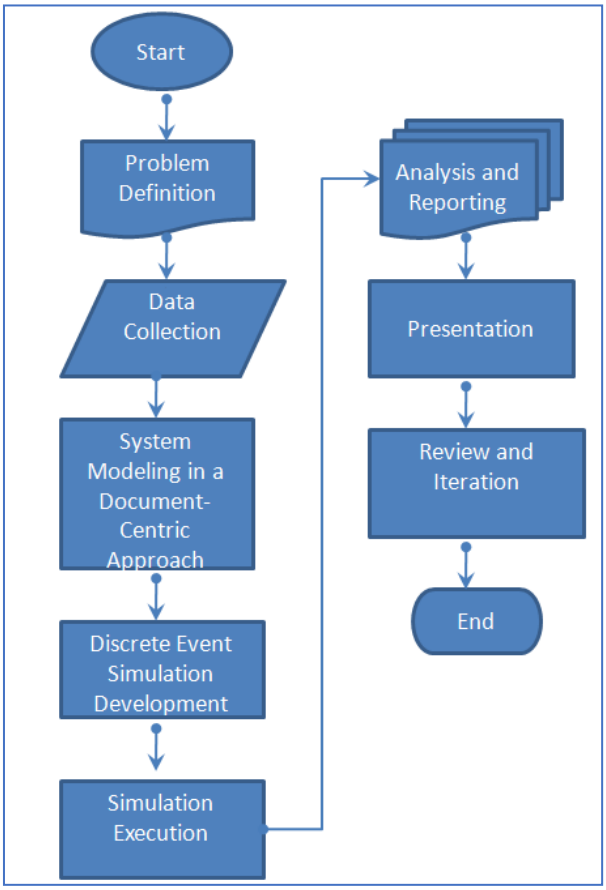

Figure 1. Traditional (Document Centric) System Engineering process flow

Problem Definition

Objective: Model a serial transfer line with three machines and two buffers to estimate system throughput, machine utilization, and average time in the system.

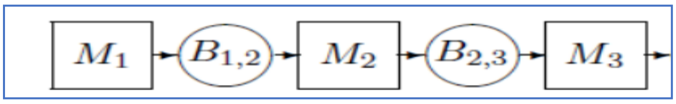

Figure 2. Serial manufacturing process flow line Diagram with 3 machines and 2 buffers

3.1 System Description:

Three machines (Machine 1, Machine 2, and Machine 3).
Two buffers with finite capacities (8 units and 10 units).
Machines have specific throughput rates, failure rates, and repair times.

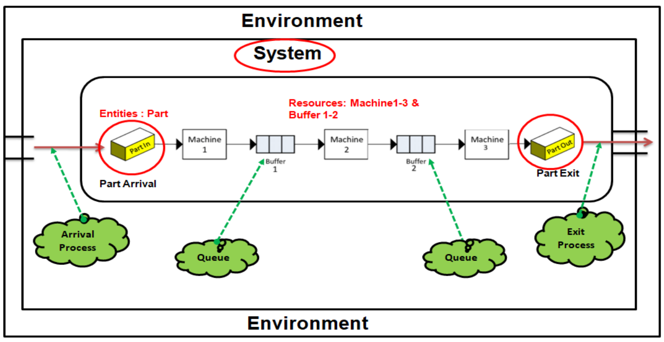

Figure 3. Overall System landscape & layout includes System boundaries, resources, and entities

4. Data Collection

This model shows a production and assembly system with pallet-based transport. The system contains assembly workstations. One part per pallet runs through the system and is processed on the stations according to the processing times. Each station has processing times and a buffer capacity.
Gather system parameters:
Machine **1**: Throughput = 72 JPH, Time between Failure = Expo(60) minutes, Time to Repair = Expo(4) minutes.
Machine **2**: Throughput = 80 JPH, Time between Failure = Expo(30) minutes, Time to Repair = Expo(4) minutes.
Machine 3: Throughput = 70 JPH, Time between Failure = Expo(60) minutes, Time to Repair = Expo(4) minutes.
Buffer capacities: 8 units for Buffer 1, 10 units for Buffer 2.

4.1 System Modeling in a Document-Centric Approach

Textual Documentation:
System Description Document:
Describe the system, including machine parameters, buffer capacities, and operational rule**s.**

Flowcharts:
Develop flowcharts to represent the sequence of operations, failure modes, and buffer behavior.

State Descriptions:
Define the states each machine and buffer can be in (e.g., Idle, Operating, Failed, Blocked).

Operational Logic:

Flowcharts:
Machine Operation:
Define the process flow for each machine. Include logic for normal operation, failure, repair, and interaction with buffers.
Buffer Operation: Define how buffers manage workpiece flow, and handle situations like full or empty conditions.

4.2 Mathematical Representation:

Use mathematical equations and descriptions to capture the stochastic behavior of failures and repairs.
Represent the buffers' capacity constraints and influence machine operations.

Manual Calculations:
Document the mathematical model for throughput calculation, expected waiting times, and system flow rates.

Key Performance Indicators (CHAVEZ 2019)**:**

To compare and evaluate the performance of the different configuration variations, different key performance indicators have been selected according to the top-level areas of improvement for System Performance.

Improving Customer Experience :

Percentage of time spent each state for each machine

$System\ Time part\ i = Finishin{:}g\ time part\ i - Arriving\ time part\ i$

Improving Efficiency

Average time in System

Cycle Time: Measures how much time is required to produce a part of the whole production line.

$Cycle\ Time\ (T) = T\ /\ Number\ of\ parts\ produced\ in\ time\ T$

Volume Flexibility

The throughput rate of the System

Indicates the ability to improve the production capacity

$Volume\ flexibility = Target\ Cycle\ Time - Cycle\ Time(MBC) / Target\ Cycle\ Time$

These performance indicators will be used for the decision criteria to select the best configuration among the different options by applying the manual configuration in the Simulation process.

4.3 Discrete Event Simulation Development

(Banks, Carson, Nelson, & Nicol 2010)

Simulation Software:
Use a DES software tool like PlantSim, Arena,Simul8, AnyLogic to develop model.
Simulation Logic:
Entities: Define entities (e.g., work pieces) that flow through the system.
Events: Model events such as machine failures, repairs, and work piece transfers.
Processes:
Model each machine as a process with parameters such as service time, failure rate, and repair time.
Buffers as queues with limited capacity.

Input Data:
Input the collected data into the simulation tool.

Verification and Validation:
Verify the logic of the simulation by checking if it correctly model system behavior.
Validate the simulation by comparing its output with expected real-world performance or simple theoretical models.

4.4 Simulation Execution

Run the Simulation:
Set up the simulation to run for a sufficient number of cycles to reach a steady state.
Consider running multiple replications to account for variability.

Performance Metrics:
Measure the throughput rate, machine utilization (percentage of time spent in different states), and average time in the system.

4.5 Analysis and Reporting

Results Documentation: Document the results of the simulation runs, including performance metrics, graphs, and tables.

Analysis:
Analyze the results to identify bottlenecks, evaluate system efficiency, and assess the impact of buffer capacities.

Recommendations:
Based on the analysis, recommend changes to improve system performance (e.g., increasing buffer capacity or adjusting machine maintenance schedules).
Presentation
Final Report:
Compile all documentation, including the system description, flowcharts, mathematical models, simulation setup, results, and analysis.

Presentation:

Prepare a presentation, summarizing the findings and recommendations
Review and Iteration
Stakeholder Review:
Present the model and results to stakeholders for feedback.
Iterate: Refine the model based on feedback and perform additional simulations if necessary.
This case study is a useful example of comparing the benefits of integrated development in a centralized modeling environment and a traditional document-centric approach in system engineering. Further research may be necessary to evaluate and compare the different case studies with the traditional system engineering approach (document-centric), and to emphasize the benefits of using an MBSE approach.

5. Results and Discussion

This case study presents a document-centric approach by documenting the level of improvement in the current manufacturing flow line based on the results and sets of KPIs defined in the problem statement. Based on the current research study, we identified that as systems become more complex, throughout the system life cycle to meet customer needs, reduce and mitigate risks, and improve system performance by analyzing the different aspects of the system.

Key Findings
In the Current research study, we used the high-level development cost ($) and delivery timeline (hrs) to document the KPI of measured benefits by using a centric approach.
Projected total efforts (delivery timeline, hours) derived from the primary tasks carried out by the resource in both methodologies.
Total Development Cost ($) has been computed for both ways by multiplying total efforts (hours) by resource cost ($) per hour.

Presumptions:
The per-hour resource cost for a system engineer with expertise in modeling and simulation is $60.

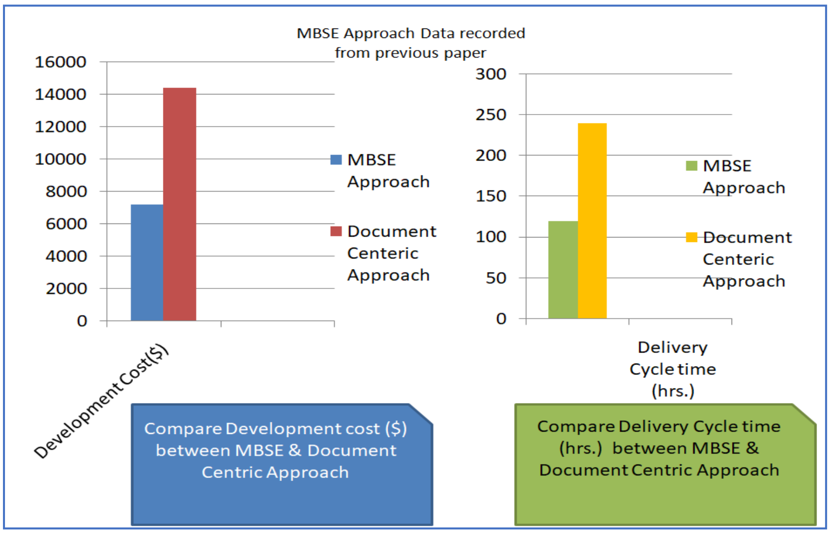

Figure 4. The development cost on the left and the delivery timeline on the right in the graph are based on the

The MBSE approach (previous paper) and KPI for document Centric approach (current paper) have been decided to measure for a same case study, (Carroll and Malins, 2016)

As part of the present research paper, the main objective is to create a report that compares the development cost ($7200 for the MBSE approach, $14400 for the document-centric approach) and delivery time (120 hours for the MBSE approach, 240 hours for the document-centric approach) of two distinct approaches (MBSE and traditional SE document-centric approach) (Carroll and Malins 2016). Comparative Analysis: The conventional SE document-centric strategy necessitates greater (almost double) efforts and development expenses compared to the MBSE technique for addressing the identical problem.

6. Conclusions and Future Research
This paper presents a method that compares the benefits of the MBSE approach (Bayer 2018) with a document-centric approach using the traditional system engineering approach and applies this method to the current case study. The current paper focuses on using a "document-centric" approach to solve the same problem and report performance based on the same set of KPIs reported in the previous paper.

In summary:
Use MBSE when designing complex systems with high traceability, consistency, and simulation requirements (INCOSE A 2014).
Use Document-Centric approaches for smaller projects or less formalized designs where flexibility is required and formal modeling isn't necessary
Potential Challenges
In the Current research study, we have identified the following potential challenges for Traditional Document-centric approach in System Engineering (INCOSE Systems Engineering Handbook 2015)
Textual

Documentation:
Information is mostly captured in textual documents such as requirements specifications, design, verification and validation documents, test plans etc.

Lack of **Traceability:**
Navigating between related documents can be challenging, particularly in complicated systems with significant manual documentation (Friedenthal, Sanford 2014)
Information Inconsistencies:
Maintaining consistency across different documents might be more complex when updating information that is not managed in a single source.

Reusability:
A document-based approach does not provide modularity or reusability, unlike model-based system engineering (Baldwin, C. Y., & Clark 2000)

Challenges in the Change Process:
Written documents leading to challenges in the change process across different phases in System Development.
Decision Making: simulation or analysis capabilities are not available in Document Based System engineering for decision-making process. This document-centric approach focuses on detailed documentation and manual processes, contrasting with MBSE's more integrated and model-driven methodology (Friedenthal, Griego, Sampson 2007). While this method is less efficient for complex systems, it provides flexibility and may be easier to implement in smaller or less formal projects. Additionally, this paper will expand in the future to explore in-depth comparisons between the document-centric approach and the MBSE approach in various intricate industrial scenarios.

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Biographies

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Sankar Sengupta: Dr. Sankar Sengupta is currently serving as a Professor in the Department of Industrial and Systems Engineering at Oakland University. He has over 30 years of teaching and research experience at Oakland University and a number of years of industrial experience in addition to his experience in academia. He has served as an invited faculty in the Engineering Management Program at the Technological University of Vienna and in Kosovo. He has authored a book on "Modeling and System Simulation" and a manuscript on "Production Systems Modeling and Performance Analysis". He has published in peer reviewed journals and presented in technical conferences.