Research Article

A Dynamic Cost Estimation Framework for Customized Manufacturing: A Case Study of the Ambulance Assembly Industry

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Abstract
The customized manufacturing industry faces a major challenge in achieving accurate and rapid cost estimation. The difficulty arises from product complexity and diverse data generated across multiple departments. This often results in scattered and outdated information that causes operational delays and reduces competitive advantage. The study proposes an Engineering Framework for Dynamic Cost Estimation through data integration with Power BI serving as the core platform. The framework was implemented and validated through a case study in the ambulance assembly industry, which represents a highly complex manufacturing sector. The quantitative results show that the proposed framework reduces the time required for ambulance type determination by 54.7% and decreases cost estimation time by 61.6%. These improvements address the specific challenges identified in the case study and also enhance overall operational efficiency. The findings provide a significant contribution to the advancement of manufacturing engineering. The research also delivers a validated model and knowledge that can be adapted to improve efficiency in other customized manufacturing sectors.

Keywords: Customized manufacturing, Data integration, Dynamic cost estimation, Power BI

1 Introduction

Proactive data management is essential for maintaining a competitive advantage in the digital economy era. Many organizations adopt information technology to manage data more effectively. Power BI is increasingly popular [1] as it enables clear analysis and presentation of complex data for decision making with applications such as Covid-19 mapping [2] and the development of a data mindset in learning environments [3]. The BI market offers diverse tools with distinct strengths. Tableau [4], [5] provides advanced visualization and flexible design, yet requires higher costs and greater learning effort. QlikView [6] supports rapid analysis but demands technical proficiency and scripting knowledge. Power BI is widely adopted due to seamless integration with the Microsoft ecosystem and a lower cost structure.

The design of an ambulance involves managing various constraints, such as limited space and the operational needs associated with emergency driving [7]. These requirements are determined by specific proposed scenarios [8]. The diverse design objectives of those ambulances impact the design capabilities. The challenge for ambulance assemblers is to quickly estimate costs and gain a commercial advantage.

The case study for the ambulance assembly company shows that current workflow processes rely heavily on email communication, which is associated with workflow inefficiency and frequent errors. Presently, summarizing ambulance characteristics takes 41,923 s (11 h and 38 min), and compiling the cost summary requires 8,342 s (2 h and 19 min). The company aims to reduce these processing times by half, setting targets of 20,962 s (5 h and 49 min) for the ambulance characteristics summary and 4,171 s (1 h and 10 min) for the cost summary (Figure 1).

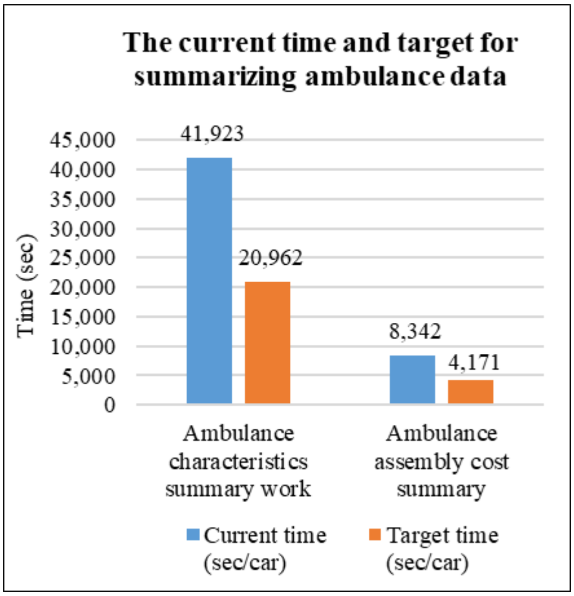


Figure 1: Current working time and reduced by 50% as the target.

The literature review indicates that a gap still exists. No evidence has been found of using Power BI to manage ambulance assembly data for reducing both characteristic summary work and cost estimation time. Consequently, the objective of this research is to utilize Power BI in managing ambulance assembly data to improve the efficiency of summarizing ambulance characteristics and estimating costs. A key benefit of this research is the substantial reduction in work time, resulting in the company giving a response to customers earlier. This offers both credibility and a competitive advantage in the market. The study is divided into four sections, each addressing a distinct aspect of the implementation process.

2 Materials and Methods

2.1 *Fishbone diagram*

The fishbone diagram, also known as a cause-and-effect diagram, was developed in 1943 [9]. The analytical tool illustrates the relationship between a specific problem and all possible contributing causes. The construction of a fishbone diagram is generally based upon four main categories of factors [10]. These factors that influence the problem are shown in Figure 2.

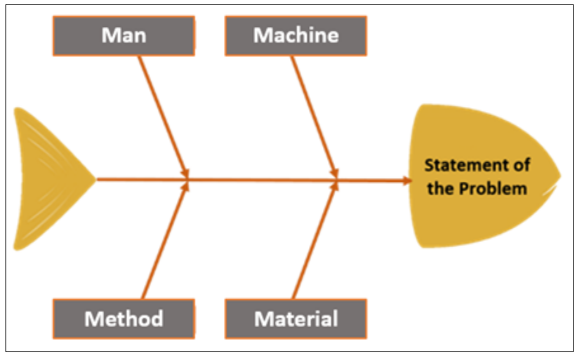


Figure 2: The 4M of the fishbone diagram.

Figure 2 illustrates a fundamental framework for a fishbone diagram. The framework categorizes potential causes of a problem into four main areas.

- Man (or People) refers to the human element, including operators, workers and other personnel involved in the process.
- Machine encompasses all machinery, equipment and tools used.
- Method describes the specific processes, procedures or steps of work.
- Material relates to all raw materials, components and consumables used in production.

2.2 *Data flow diagram (DFD)*

The Data Flow Diagram (DFD) [11] is a graphical technique that is easy to understand and effective for defining system boundaries. It is valuable for communicating system knowledge to users and also functions as part of the overall system documentation. The documentation explains the logic that underlies data movement. A DFD illustrates the interconnected nature of processes and presents where data originates, where it is transferred and where it is stored. Multiple notations are available for constructing a DFD and the practice has developed since the early period of structured systems. The evolution occurred alongside high-level programming languages such as COBOL [12]. The analysis and creation of a DFD require the use of a defined set of symbols [13]. These symbols are shown in Table 1.

Table 1: Symbols used in drawing for DFD.

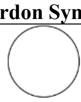
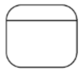
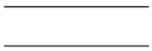
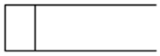
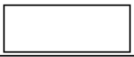
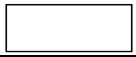
Symbol Name	DeMarco & Yourdon Symbols	Gane & Sarson Symbols
Process		
Data Store		
Data Flow		
External Entity		

Table 1 demonstrates two different sets of notations for creating Data Flow Diagrams (DFD). These notations are defined by DeMarco & Yourdon and Gane & Sarson. Both are graphical methods used in software engineering and systems analysis to represent data flow through a system. The key difference between them lies in the symbols used to represent core system components.

- **Process**: Depicted as a rectangle with rounded corners. It represents an activity or function that transforms data from input to output.
- **Data Store**: Presented as two parallel lines or an open-ended rectangle. It symbolizes a location where data is stored. Examples include a file or a database.
- **Data Flow**: Represented by a line with an arrowhead. This symbol indicates the direction of data movement between process data stores and external entities.
- **External Entity**: Symbolized by a square or rectangle. It represents an external person, organization, or destination for data. This entity interacts with the system but remains outside its scope.

2.3 *Power BI program with dynamic cost estimation*

2.3.1 Power BI

Power BI [14] is a powerful data analysis and visualization tool developed by Microsoft. It provides a comprehensive set of features. These features allow users to transform raw data into interactive reports, dashboards and actionable insights. Key aspects of Power BI as a data analysis tool include its ability to connect to various data sources, perform data modeling and create compelling visualizations to support decision-making [15]. Its user-friendly interface facilitates easy data updates and ensures accessibility from multiple devices. These devices include computers, mobile phones and tablets. A primary function of Power BI is to connect to diverse data sources such as Excel files, databases and websites. This follows the principle of “Design Once View Anywhere.” This design flexibility [16] allows users to create reports once and access them seamlessly from any location at any time. Power BI has two main components. The first component is PowerBI.com. It is a web-based platform also accessible through mobile devices. The second component is Power BI Desktop. This is a desktop application designed for creating and publishing dashboard reports.

2.3.2 Dynamic cost estimation

- **Method Overview**: The method begins by establishing a project dynamic cost estimation [17] model. This model incorporates a comparison layer. The layer assesses if the estimated cost exceeds a predefined maximum cost value. Key steps in this overview include initial particle swarm construction, algorithm model building, weight coefficient correction and fitness value determination.
- **Method implementation**: The dynamic estimation method involves five key components. A key component is the dynamic model of project cost. In this model, foundation engineering is treated as a comparison layer. The foundation pit cost serves as an example. From this example, characteristic factors are selected to establish a project cost system.

2.4 *Google drive*

Cloud computing services have been widely adopted by both individuals and organizations in recent years [18]. Google Drive is a prominent cloud storage service among them [19]. It has revolutionized how users access and share files [20]. It enables users to store their files online and access them from any device with internet connectivity. Users can also share files with others for collaboration. The service offers an intuitive interface. It integrates seamlessly with other Google applications. These applications include Google Docs Sheets and Slides [21]. Users can upload a wide range of file types, collaborate in real time and efficiently manage their documents. Google Drive provides a generous amount of free storage. Options are available to purchase additional space if needed. The service incorporates robust security measures to safeguard user data.

2.5 *Hypothesis test*

Hypothesis testing [22] often employs statistical techniques to compare group means. One such method is the T-test. This test compares a single sample group mean to a population mean. It can also compare the means of two sample groups. These groups can be related or independent. The validity of this test relies on key assumptions. The sample must be randomly selected from a normally distributed population. It is also critical that the population variance is typically unknown. Detailed comparisons involving two means can be categorized into three distinct types [23].

- **Null hypothesis (H_0)**: The definition indicates that there is no difference between population group 1 and population group 2. There is no relationship between the two groups. In this research study. Define μ_1 as the time for defining the ambulance type. μ_2 represents the time for ambulance cost estimation. Δ_0 represents the difference in value between the two groups of ambulances.
- **Test statistics**: The calculation determines whether the means of two groups are different. The groups under consideration are population 1 and population 2. The outcome of the calculation informs the decision to accept or reject the null hypothesis. The pooled variance S_p is calculated to evaluate the variability of data between group 1 and group 2. The result of the calculation indicates that significant differences exist between the two populations. $\bar{X}_1$ represents the mean time for defining ambulance type. $\bar{X}_2$ represents the mean time for ambulance cost estimation. n_1 represents the number of ambulances in sample group 1. n_2 represents the number of ambulances in sample group 2.
- **Alternative hypothesis (H_1)**: The alternative hypothesis suggests a difference or relationship exists between the variables under study. This research specifically compares the current system with the new system for ambulance type and cost analysis. The alternative hypothesis is presented in three formats.
- **Format 1; H_1: $\mu_1 - \mu_2 \neq \Delta_0$ (Two-tailed test)** The mean time for defining the ambulance type is different from the mean time for ambulance cost estimation.
- **Format 2; H_1: $\mu_1 - \mu_2 > \Delta_0$ (One-tailed test)** means the mean time for defining the ambulance type is greater than the mean time for ambulance cost estimation.
- **Format 3; H_1: $\mu_1 - \mu_2 < \Delta_0$ (One-tailed test)** means the mean time for defining the ambulance type is less than the mean time for ambulance cost estimation.
- ***p*-value and rejection criterion for fixed-level tests:** A *p*-value less than 0.05 indicates a significant difference. The difference is between the time for defining the ambulance type and the time for ambulance cost estimation. The result leads to the acceptance of the alternative hypothesis (H_1). Conversely, a *p*-value greater than or equal to 0.05 suggests insufficient evidence. Therefore, the null hypothesis (H_0) cannot be rejected. The alternative hypothesis (H_1) is not accepted.

2.6 *Satisfaction evaluation level*

The 5-level system performance satisfaction assessment form [24] is used to collect data for analysis. The collected data support the evaluation of user satisfaction with system performance. The analysis is performed by calculating the average score for each evaluated item [25]. Evaluators are required to mark the appropriate box on the 5-level satisfaction scale. The interpretation of the scoring system is presented as follows.

- 4.50–5.00 Indicates a highly satisfactory system.
- 3.50–4.49 Signifies a satisfactory system.
- 2.50–3.49 Represents a moderate system.
- 1.50–2.49 Indicates a fair system.
- 1.00–1.49 Signifies a system requiring improvement.

2.7 *Standard deviation (SD) level*

SD is a statistical measure that quantifies the dispersion of data within a sample relative to the mean. The calculation of SD is performed using a sample, which represents a subset of the population [26].

- **High SD**: Indicates high dispersion and presents that the data values vary significantly from the mean.
- **Low SD**: indicates low dispersion and presents that the data values are closely clustered around the mean.

The standard deviation (SD) [27] of a sample can be calculated by applying the mathematical (Equation (1)).

$$SD = \sqrt{\frac{\sum(X_i-\bar{X})^2}{n-1}} \quad (1)$$

Where X_i is Each value of the data in the data set.
$\bar{X}$ is Mean of the dataset.
n is Sample size of observations.

2.8 *Problem analysis*

A multidisciplinary team of five members was convened for the case study to address challenges related to ambulance assembly costs. The team consisted of an engineering manager, an assembly supervisor, a cost controller, a product specialist, and representatives from the marketing department. The group conducted a root cause analysis of the problem using a fishbone diagram. The diagram is demonstrated in Figure 3. The analysis was guided by problem assessment criteria that are shown in Table 2.

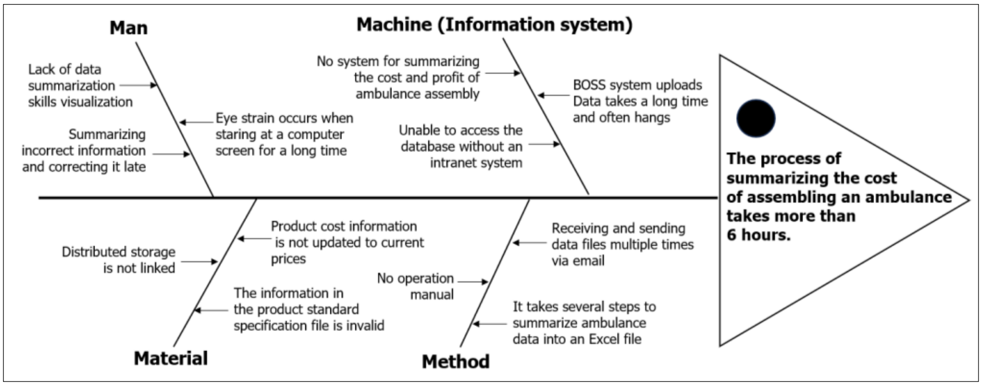


Figure 3: Fishbone diagram of root cause analysis using the 4M principle.

Table 2: The criteria of assessment topic for 4M.

Assessment Topic 1: Operation • **Score 1** means easy each team member can perform. • **Score 2** means moderate each team member can perform. • **Score 3** means difficult and hiring a subcontractor is needed. • **Score 4** means very difficult and hiring a sub-contractor is desperately needed.	**Assessment Topic 2: Operational Cost** • **Score 1** means easy each team member can perform. • **Score 2** means moderate (62–154 USD). • **Score 3** means high (154–308 USD). • **Score 4** means very high (more than 308 USD).
Assessment Topic 3: Operation Duration • **Score 1** means less than 1 month. • **Score 2** means moderate 1–3 months. • **Score 3** means high 4–6 months. • **Score 4** means more than 6 months.	**Assessment Topic 4: Opportunity to Solve Problems Successfully** • **Score 1** means Low (0–25%). • **Score 2** means Medium (26–50%). • **Score 3** means High (51–75%). • **Score 4** means Very High (76–100%).

The evaluation criteria [28], [29] from Table 2 are applied to summarize the evaluation scores. The summary produces a problem-solving ranking that is based on the causes identified in the fishbone diagram.

2.9 *Measure the working time*

Determining the appropriate sample size is a crucial first step in any time study. A major challenge is the inherent variability within work cycles. Such variability may result from timing errors or inconsistent work methods. Achieving a consistent standard time is therefore difficult. The collected data often exhibits dispersion. It is essential to gather preliminary data to estimate this variability. Preliminary estimation supports the calculation of the optimal number of recording cycles required for a reliable study. One established approach is the Maytag theory [30], which determines the required number of recordings based upon the range of initial sample data [31]. The procedure consists of several steps. The cycle time defines the number of initial time measurements. For cycles lasting less than 120 seconds, an initial sample of ten measurements is recorded. For cycles longer than 120 seconds, a sample of five measurements is taken. The range is then calculated using Equation (2).

$$R = \text{MAX time} - \text{MIN time} \quad (2)$$

Find X-bar ($\bar{\boldsymbol{X}}$) in the Equation (3).

$$\bar{\boldsymbol{X}} = \frac{\sum x_i}{n} \quad (3)$$

This Maytag table is calculated from the relationship equation $\left(\frac{R}{\bar{X}}\right)$ as Equation (4).

$$\sigma = \frac{\bar{R}}{d_2} \tag{4}$$

Where $\bar{R}$ is Average Range.
d_2 is Factor for C.

2.10 *Database in power BI*

The data flow diagram (DFD) [32] is presented in Figure 4. It illustrates the complex procedures of the Incoming Materials Inspection process. The process currently operates without a supporting management information system (MIS) [33]. The manual workflow is impeded by a disorganized file and folder structure that prevents immediate data retrieval and creates a significant operational bottleneck.

A new database was designed and finalized to address these challenges. The solution was developed using the Power BI program. The final design is shown in Figure 5.

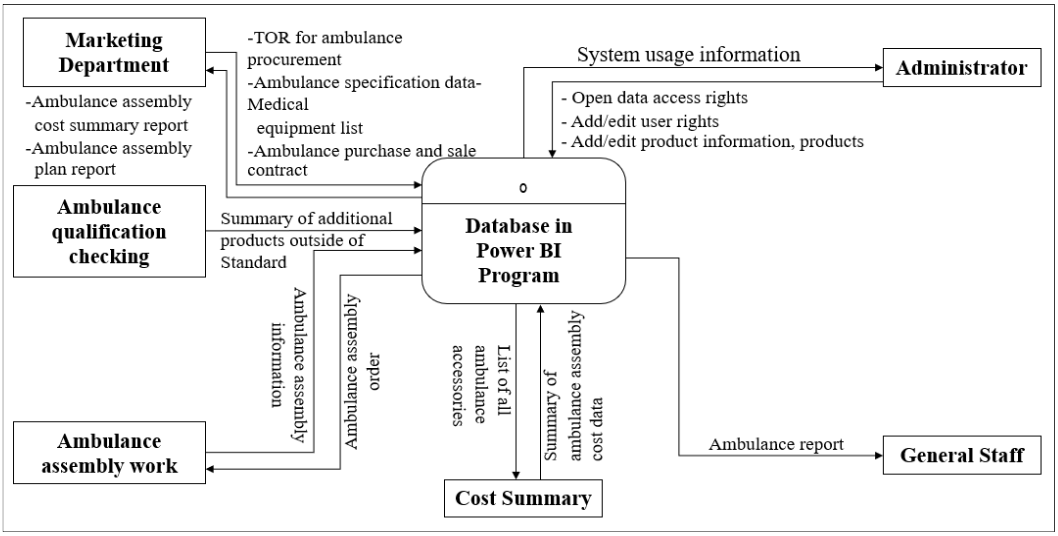


Figure 4: Data flow diagram (DFD).

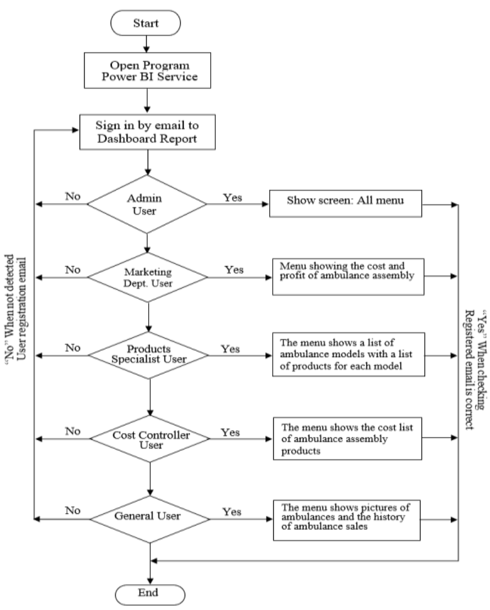


Figure 5: Algorithm for the Power BI program.

3 Results and Discussion

3.1 *Comparing the development*

Previous studies demonstrate the effectiveness of Power BI. One study reported that a Power BI dashboard reduced student behavior analysis time by 33% [3]. Another study indicated that Power BI can increase decision-making speed by up to 25% through real-time interactive dashboards [14]. A separate paper reported high positive feedback rates for Power BI [34] without specifying a single aggregate improvement percentage. The feedback included 85% for effectiveness in reporting and visualization 78% for impact on business decisions and 80% for real-time analytics. In comparison, the Power BI solution developed in this research significantly outperformed these previous results. The time required for defining ambulance types was reduced by 54.7% and the time required for cost estimation was reduced by 61.6%.

These findings highlight the substantial efficiency achievable through the proposed framework.

3.2 *Time collection and data testing*

A time study was conducted to evaluate the outcomes of the new Power BI program. A stopwatch was used to record the time that staff spent on two key processes. These processes included defining the ambulance type and estimating the cost. Data were collected for a sample of ten ambulances to enable a statistical comparison. The data are shown in Table 3 and 4. The collected data were used to perform a hypothesis test. The test determined whether the average working times under the new system differed significantly from the previous system and whether the sample groups were independent.

Table 3: Time of defining ambulance type (sec).

No.	Curent System	New System	No.	Curent System	New System
1	41,837	18,982	6	42,548	20,472
2	40,621	19,652	7	41,126	21,228
3	41,274	20,143	8	41,927	20,634
4	41,723	18,158	9	40,452	19,693
5	40,894	19,557	10	41,083	19,874

Table 4: Time of ambulance cost estimation (sec).

No.	Curent System	New System	No.	Curent System	New System
1	8,320	3,210	6	8,414	3,189
2	8,387	3,351	7	8,366	3,341
3	8,284	3,289	8	8,324	3,626
4	8,411	3,781	9	8,117	3,545
5	8,423	3,469	10	8,243	3,414

3.3 *Hypothesis testing*

This section compares the current system and the new system. The comparison focuses on the time required for defining ambulance type data. The null hypothesis (H_0) is set as follows. The average time for defining the ambulance type in the current system is equal to the average time for the same task in the new system.

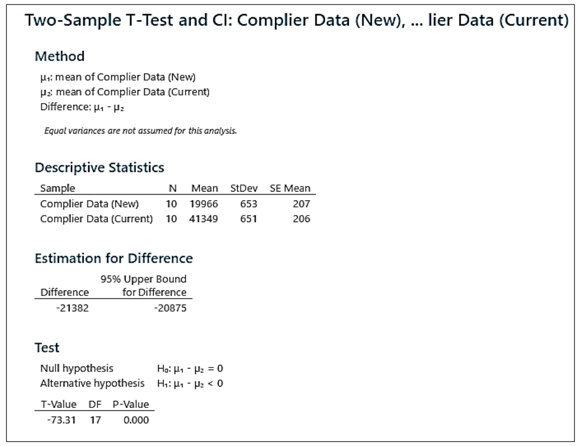
- **Null hypothesis**; H_0: μ_1 - μ_2 = 0

The alternative hypothesis (H_1) is also established. It states that the average time for defining the ambulance type in the new system is less than the average time for the same task in the current system.

- **Alternative hypothesis**; H_1: μ_1 - $\mu_2 \neq 0$

The variable μ_1 represents the average time for defining the ambulance type. This is measured using the current system. The variable μ_2 represents the average time required to perform the same task using the new system.

3.4 *Data collection and statistical analysis*


Two-Sample T-Test and CI: Complier Data (New), ... lier Data (Current)

Method

μ_1: mean of Complier Data (New)
μ_2: mean of Complier Data (Current)
Difference: μ_1 - μ_2

Equal variances are not assumed for this analysis.

Descriptive Statistics

Sample	N	Mean	StDev	SE Mean
Complier Data (New)	10	19966	653	207
Complier Data (Current)	10	41349	651	206

Estimation for Difference

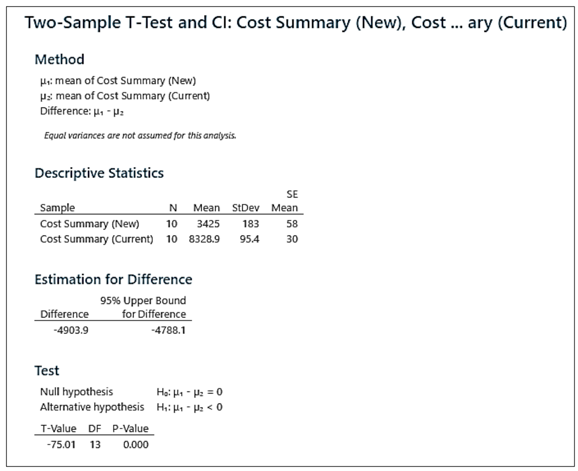
Difference	95% Upper Bound for Difference
-21382	-20875

Test

Null hypothesis H_0: μ_1 - μ_2 = 0
Alternative hypothesis H_1: μ_1 - μ_2 < 0

T-Value	DF	P-Value
-73.31	17	0.000

Figure 6: Two Sample T-Test time of defining ambulance type.


Two-Sample T-Test and CI: Cost Summary (New), Cost ... ary (Current)

Method

μ_1: mean of Cost Summary (New)
μ_2: mean of Cost Summary (Current)
Difference: μ_1 - μ_2

Equal variances are not assumed for this analysis.

Descriptive Statistics

Sample	N	Mean	StDev	SE Mean
Cost Summary (New)	10	3425	183	58
Cost Summary (Current)	10	8328.9	95.4	30

Estimation for Difference

Difference	95% Upper Bound for Difference
-4903.9	-4788.1

Test

Null hypothesis H_0: μ_1 - μ_2 = 0
Alternative hypothesis H_1: μ_1 - μ_2 < 0

T-Value	DF	P-Value
-75.01	13	0.000

Figure 7: Two Sample T-Test time of ambulance cost estimation.

Figures 6 and 7 present a comparative performance analysis using two-sample T-tests for the new system versus the current system. The results indicate statistically significant improvements in processing times. Improvements were observed in both defining the ambulance type and estimating the ambulance cost. The null hypothesis was rejected in both independent tests because the *p*-value was less than 0.05. The findings confirm that the new system represents a significant improvement over the current system.

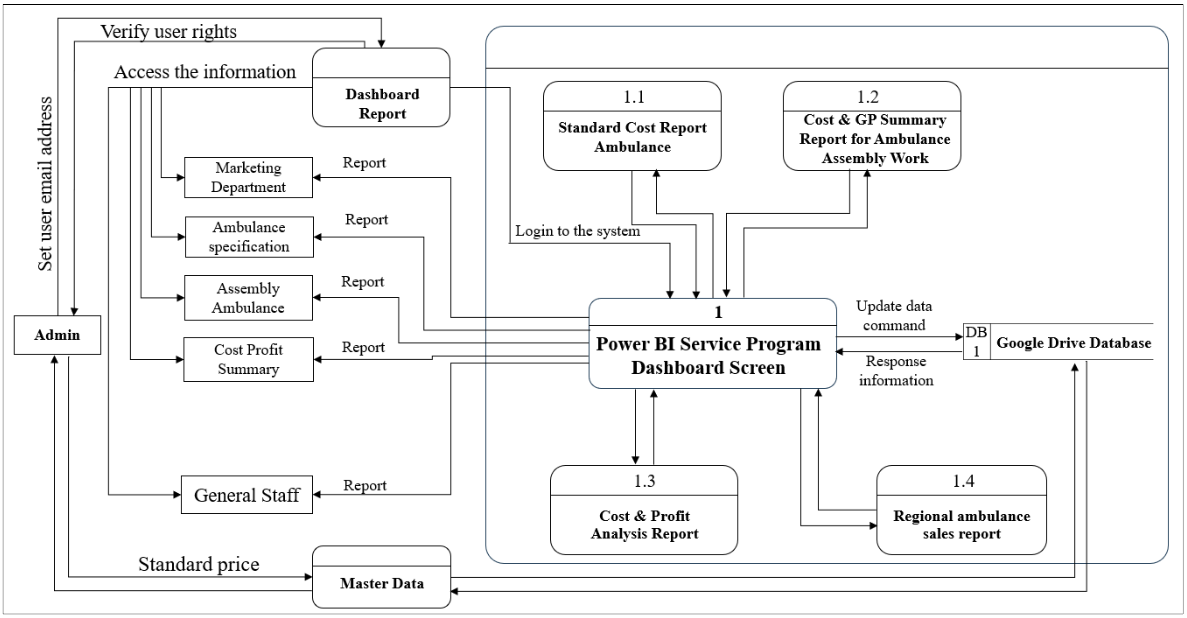


Figure 8: DFD New database Power BI Program.

3.5 *Data management system*

3.5.1 Google Drive

Google Drive was used as the main data storage database for this research.

3.5.2 Power BI

The DFD of the new database in the Power BI program is demonstrated in Figure 8.

Figure 8 shows user interaction pathways and data inputs from multiple departments. The diagram highlights the central processing logic within the Power BI service. Analytical reports are generated directly from the integrated Google Drive database.

3.6 *Initial data management system*

The application's initial screen displays the program name and creator. A user must provide credentials for authentication to access the system. These credentials are an email address and a password. The user then clicks the “Sign in” button. The system validates the information. Successful verification redirects the user to the main program screen.

3.7 *Dynamic data sharing ambulance assembly cost summary dashboard report*

Access to the program is limited to authorized personnel to protect data integrity and security. All users must complete a mandatory registration process before entry. The system includes a dynamic cost estimation function that supports real-time collaborative updates across all departments. The integration ensures that cost estimates rely on the most current and comprehensive information from stakeholders. Power BI is organized into two main pages, each with a distinct function. The first page displays standard costs. The second page shows a dashboard for cost and gross profit (GP) analysis, as shown in Figures 9 and 10.

3.8 *Comparative current & new system*

The implementation of the Power BI program resulted in substantial efficiency gains. Overall, working time was reduced by 54.7%. This represents a decrease from 11 h 38 min and 43 s (41,923 s) to 5 h 16 min and 12 s (18,972 s). An even greater improvement was observed in the cost estimation process, experiencing a 61.6% time reduction from 2 h and 19 min down to 53 min. The program also streamlined the workflow by reducing operational steps by 24% (from 29 to 22) and eliminating email-based data transfers, as demonstrated in Figure 11.

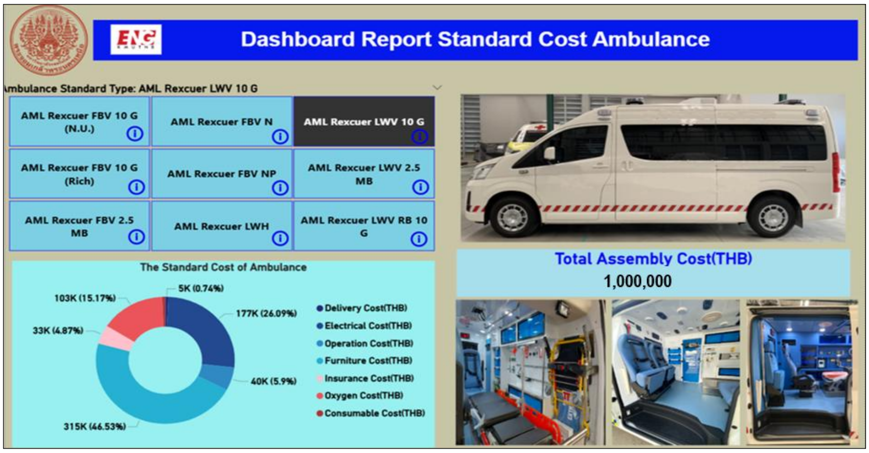


Figure 9: Dashboard report standard cost.

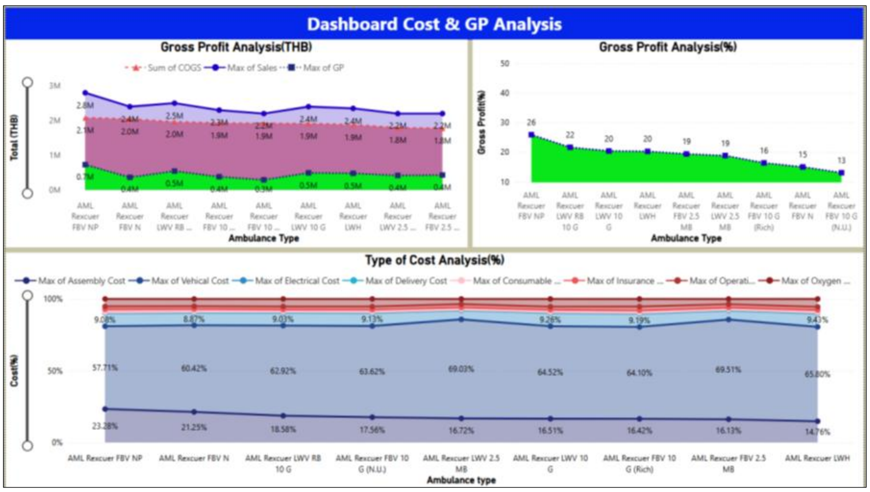


Figure 10: Dashboard report cost and GP analysis.

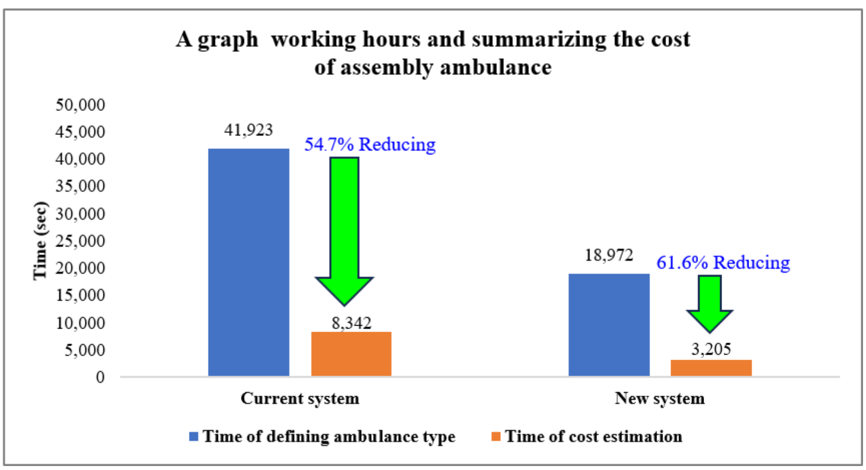


Figure 11: The comparison of the results between the current and new systems.

Figure 11 shows that the time required for both processes was reduced by more than 50% overall. This significant improvement is primarily attributed to the program's ability to integrate the product. This real-time data access reduces manual work steps by minimizing time spent searching for price information and by eliminating the need for extensive data revisions.

3.9 *System usability evaluation results*

A sample group of 11 users completed a questionnaire evaluating three aspects of system usage. The evaluation yielded the following satisfaction scores.

- **System Usage** received a mean score of $\bar{x}$ = 4.20 representing a satisfactory evaluation level.
- **System Design** received a mean score of $\bar{x}$ = 4.09 representing a satisfactory evaluation level.
- **System Display** received a mean score of $\bar{x}$ = 4.36 representing a satisfactory evaluation level.

The system display aspect received the highest rating. The overall average score across the three aspects was 4.22. This score corresponds to a satisfactory rating.

4 Conclusions

An Engineering Framework for Dynamic Cost Estimation was developed and validated for the customized manufacturing sector. The framework integrates engineering data with a business intelligence platform to address persistent inefficiencies in cost analysis and workflow management. A case study in ambulance assembly provides empirical validation. The result indicates a 54.7% reduction in total process time and a 61.6% reduction in cost analysis time. The outcomes confirm the framework as an effective technological solution that improves process reliability, reduces error rates and enhances communication across departments.

The contribution extends beyond a single application. The framework offers a scalable model suitable for other customized manufacturing industries that encounter similar challenges in data management and cost estimation. Future work should focus on integration with Enterprise Resource Planning (ERP) systems and the inclusion of real-time supply chain data. Such extensions can establish a comprehensive engineering management platform designed to further improve profitability and operational efficiency.

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Author Contributions

A.K.: provided the project’s conceptualization methodology and research design; T. R.: conducted the investigation data curation and data analysis. Both of them were also responsible for writing the original draft and performing all subsequent reviews and editing. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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