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EFFICIENCY OF CMMS (COMPUTERIZED MAINTENANCE MANAGEMENT SYSTEM) PROJECT STAGES WITH K-MEANS

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ABSTRACT
This study scrutinized four CMMS (Computerized Maintenance Management System) development projects using the K-Means clustering method to evaluate stages that require improvement by the GrX team. The projects under consideration were named Tim, Lix, Akb, and Mnk. The results indicated that the Tim project leaned more towards efficient CMMS development stages, while the Lix and Akb projects were predominantly in less efficient clusters at the implementation stages. The Mnk project had stages in less efficient clusters located at stages other than implementation processes. This suggests that each project has its unique challenges in achieving efficiency. However, the overarching conclusion is that the GRX team needs to enhance efficiency in the CMMS software development process. Several stages need to be evaluated, particularly the "data analysis and coordination" and "implementation of asset, work order, preventive and spare part modules" stages. Inefficiency occurs when the designing work time has a value lower than twice the workload. The K-Means algorithm was employed in the clustering process because it was believed that the data to be grouped was well-suited for implementation with this algorithm. The variables involved in this study were time and workload. This research provides valuable insights into the efficiency of CMMS development projects and offers a roadmap for future improvements.

I. INTRODUCTION

CMMS, or Computerized Maintenance Management System, is a type of software commonly used in industry to help maintain all the equipment in a factory [1], [2]. CMMS helps reduce the occurrence of equipment failure. It is part of the ERP (Enterprise Resource Planning) application [3], but CMMS focuses more on features related to maintaining industrial equipment. Industries that use CMMS include healthcare, transportation, manufacturing, and even government. These industries all have a need for asset maintenance, so CMMS is not limited to just manufacturing. However, many manufacturing industries use CMMS because they have many expensive assets and spare parts, and equipment failure can be very costly. CMMS helps maintenance teams in companies manage finances, track maintenance costs, and predict future costs to prevent them from ballooning by reducing downtime on equipment

There are many CMMS software options available on the market [4]. However, not all features are well-executed or used properly by users. This is because some features in a CMMS may not have standard functions that align with the operations of an industry. As a result, many industries implement CMMS but experience implementation failures in their companies. Therefore, most companies use a modified version of CMMS during development that is in line with their company's work culture or organizational culture. Most users of this modified CMMS system are private companies. Private companies are expected to have low costs but still achieve good results in implementing CMMS [5]. In addition, the software used should be able to follow the workflow concept of machine maintenance in a company [6]. While large CMMS systems like Microsoft and SAP are well-known and reliable, they can sometimes be rigid and difficult to implement within a company's culture. As a result, many CMMS users look for applications that can be modified without breaking the bank and are even more reliable than well-known CMMS applications, especially for private companies in Indonesia. One such CMMS software product from Indonesia is GrX CMMS, produced by GrX company located in Gresik. Many of GrX's clients are private companies looking for an application concept that can be adapted to their company's maintenance organization's work culture. This also presents a challenge for the GrX team, who are tasked with completing CMMS features on time and in line with the maintenance culture concept of the companies they serve. There can be difficulties at various stages of application development. However, the GrX team has not yet found a focus stage that often experiences bottlenecks and requires a long process to resolve. So far, the GrX team has used an estimated timeline concept and has not focused on which timeline stage is a high priority and which is a low priority. Therefore, an analysis of an existing timeline schedule is needed to develop a decision-making concept for determining workload and time in the process of completing a stage in CMMS development, [7], [8]. The framework from the timeline processing results will be used as a concept for creating timeline schedules for future GrX projects.

Grouping the stages of a CMMS project, we use the clustering method. This method is used to group variables into predetermined groups using a simple data model. In this study, the timeline stages of each project will be grouped into two types of groups: efficient and less efficient. The GrX team will focus on the stages that mostly fail in the process of determining workload and time. This will allow for corrections to be made to a project's timeline schedule. The algorithm used in the clustering process is K-Means [9], [10], [11], [12], [13], [14] , because the researchers believe that the data to be grouped is well-suited for implementation with this algorithm. This is because the project timeline data is simple, and K-Means has good reliability and accuracy in processing simple data without involving too many variables, so there is no need to reduce unnecessary variables that would cause the points between variables to become further apart. The variables involved in this study are time and workload. To strengthen the results in future research, a comparison process with another clustering method is needed. If the same results are obtained, it can be said that clustering with the K-Means method is suitable for use in this case. However, in this study we will see the cluster results using several projects with K-Means and focus on less efficient stages.

II. RESEARCH METHODS

In Figure 1, the process in this study is shown, which is first to collect the entire timeline of the CMMS project and then perform a pre-processing process to validate the data and review the data to remove unnecessary data and obtain the centroid of the data to be processed. After performing the pre-processing process, it can be continued with the process of implementing data in calculations using the K-Means method.

Data collection is done by collecting actual data from projects involved in research, while these data are in the form of project timelines consisting of stages presented in Table 1. Table 1 shows a list of activities from the entire timeline of the GrX team project, where this list of activities covers various stages, starting from the kick-off meeting, data analysis and coordination, implementation and development of certain modules such as user management, assets, work orders, preventive maintenance, and spare parts module.

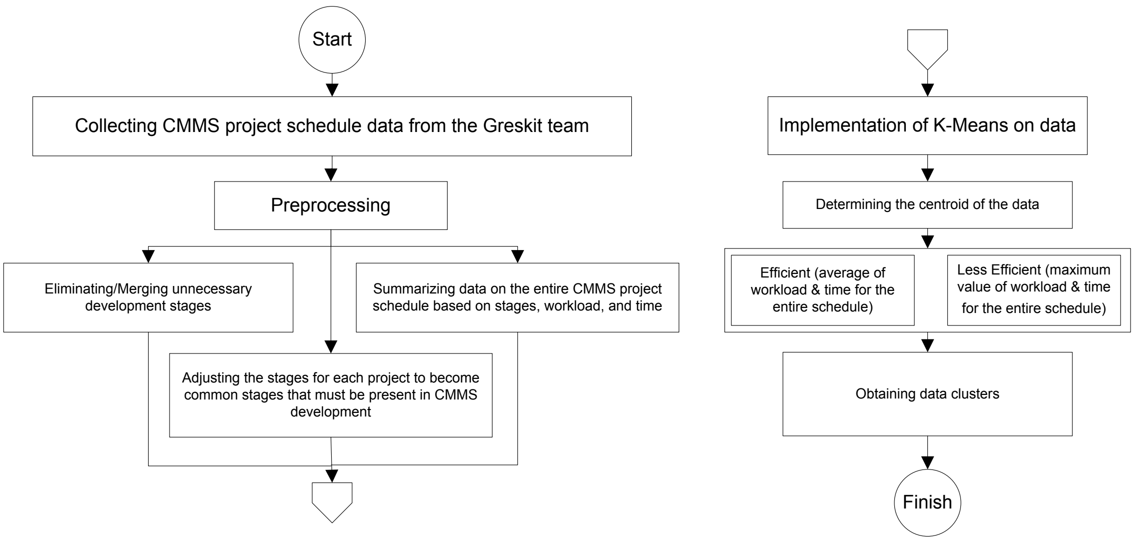

Figure 1. Research Steps

After all modules are implemented and tested, the system is then uploaded to the server/cloud and run. After that, training is given to users to ensure they can operate the system properly. The last stage is monitoring and improvement to ensure the system runs well. And these activities were carried out on four projects as a process of observation and data collection, namely Tim, Lix, Mn, Akb projects.

TABLE 1
PROJECT WORK STAGES

No	Activity
	Administration (Kick Off Meeting)
	- Kick Off Meeting *
	Data Analysis And Coordination
	- User Management
	- Data Reporting And Interconnecting
	- Data Asset & Spare Part
	- Data Pm Dan Work Order
	Implementation And Development Phase
1	**User Management**
	- Setting User Level
	- Customer Approval
2	**Asset Module**
	- Equipment Data Table Preparation
	- Data Table - Cmms Preparation
	- Data Upload & Development
	- Run Test & Adjusment
	- Customer Approval
	- Training Asset Modul & Work Order *
3	**Work Order Module**
	- Equipment Data Table Preparation
	- Data Table - Cmms Preparation
	- Data Upload & Development
	- Run Test & Adjusment
	- Customer Approval
	- Training Preventive Maintenance Modul *
4	**Preventive Maintenance Modul**
	- Equipment Data Table Preparation
	- Data Table - Cmms Preparation
	- Data Upload & Development
	- Run Test & Adjusment
	- Customer Approval
	- Training Preventive Maintenance Modul *
5	**Sparepart Modul**
	- Equipment Data Table Preparation
	- Data Table - Cmms Preparation
	- Data Upload & Development
	- Integration
	- Run Test & Adjusment
	- Customer Approval
	- Training Sparepart Modul *
	Deployment (Go Live) Server/Cloud
	- Upload Cmms To Server/Cloud
	- Run Test & Adjusment
	- On Site Training
	- Training Cmms Operasional
	Monitoring And Improving
	- Monitoring And Improving *

Based on this table, each activity can consist of several activities, but not all activities are involved in the clustering process of activity data. Only eight activities by eliminating activities that are in the same group and activities that are not significant enough to be observed in this study. And this is what is called the preprocessing stage in this study. From several activities in Table 1, eight activities were obtained which can be seen in Table 2

TABLE 2
ACTIVITIES AFTER PREPROCESSING

No	Activity
1	**Data Analysis And Coordination**
	Implementation And Development Phase
2	A. User Management
3	B. Asset Module
4	C. Work Order Module
5	D. Preventive Maintenance Modul
6	E. Sparepart Modul
7	**Deployment (Go Live)**
8	**Monitoring And Improving**

Based on Table 2, we can see that there are eight activities that will be evaluated for cost consumption efficiency using the K-Means method, namely data analysis activities, implementation consisting of user management, asset module, work order module, preventive maintenance module, spare part module, deployment process and application monitoring. After preprocessing, the next step is to summarize the data based on the project load and time. The data summary is obtained from the preprocessing process and then obtains the time consumption and workload variables. After going through this stage, we get an estimate of the time and workload presented in Table 3. There are four projects that will be analyzed and we disguise the project names with Tim, Lix, Akb, and Mn.

TABLE 3
WORKLOAD AND TIME FROM THE GRX TEAM TIMELINE

Plan/Task	**Tim.** Weight	Weeks
Data Analysis And Coordination	16	3
Implementation and Development User Management	5	3
Implementation and Development Asset Module	16	7
Implementation and Development Work Order Module	16	7
Implementation and Development Preventive Module	18	7
Implementation and Development Spare Part Module	25	7
Deployment (Go Live)	11	5
Monitoring and Improving	2	2
Plan/Task	**Lix.** Weight	Weeks
Data Analysis And Coordination	15	8
Implementation and Development User Management	3	4
Implementation and Development Asset Module	15	7
Implementation and Development Work Order Module	21	6
Implementation and Development Preventive Module	21	6
Implementation and Development Spare Part Module	18	9
Deployment (Go Live)	4	8
Monitoring and Improving	2	2
Plan/Task	**Akb.** Weight	Weeks
Data Analysis And Coordination	5	5
Implementation and Development User Management	5	3
Implementation and Development Asset Module	19	5
Implementation and Development Work Order Module	18	5
Implementation and Development Preventive Module	18	5
Implementation and Development Spare Part Module	19	5
Deployment (Go Live)	4	2
Monitoring and Improving	1	1
Plan/Task	**Mn.** Weight	Weeks
Data Analysis And Coordination	17	4
Implementation and Development User Management	6	2
Implementation and Development Asset Module	15	6
Implementation and Development Work Order Module	20.5	9
Implementation and Development Preventive Module	17	9
Implementation and Development Spare Part Module	9	6
Deployment (Go Live)	3	1
Monitoring and Improving	2	2

And from the workload and work time in Table 3, it will be used as the basis for calculations in the K-Means process which will be explained in the next sub-chapter. Before explaining the K-Means process, there are several points of explanation related to the timeline and CMMS as follows.

2.1 Project Timeline

A timeline is an activity that has been scheduled by a project manager to complete tasks that have been agreed upon with the customer. This timeline is used by project managers and customers so that the tasks being worked on can be completed on time, or for an analyst it can be used to find out how much progress has been made by the team in completing tasks [7], [8], [15]. If the tasks completed are not in accordance with the specified time, in the future it can be used to analyze the problems that occur so that the time required becomes longer and does not match the previously agreed time. This timeline is useful as a notification for both parties, both from the project team and customers, to adjust the tasks that have been made with sub-tasks that may arise from these tasks still within the specified schedule range in a task [16], [17]. Basically, if there are tasks that may arise not according to the specified schedule, it is likely that both time and cost will increase. For example, if the schedule of a project exceeds the specified time limit, it will add to the fee cost of the project team, waste time that should have been allocated to another project, but still persists in the previous project. Figure 2 shows the project timeline.

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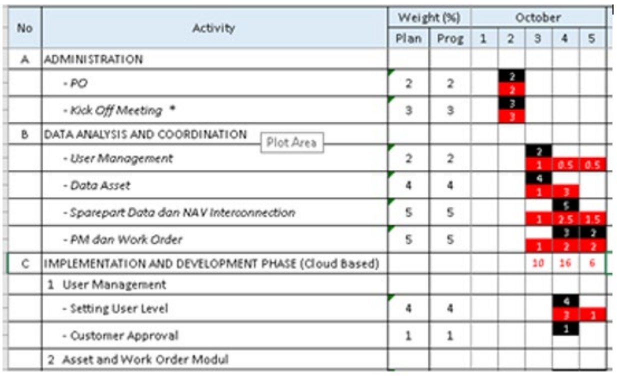

Figure 2. Project Timeline

Based on the project timeline, the calculation of the grouping process of a project is determined based on two main variables in a timeline, namely workload and progress as presented in Figure 2.

2.1.1 Weight

The measurement of workload in a timeline, especially CMMS, is determined based on how difficult a task will be to work on. In addition, it is also based on the possible time required to develop a feature. As can be seen in Figure 2, administrative tasks are smaller than data analysis and coordination tasks. Of course, the first task is smaller in portion because when viewed from sub-tasks, this task is less than the second task. In addition, the feature development process is more complex in the second task, where the development process has started at this stage. While in the previous stage it was still focused on the administrative process. As for the factors that allow a workload to be rated high in the CMMS process :

a. Number of sub-tasks
b. The level of difficulty in a task
c. Completion time of the task

In Figure 3, there is a red block that shows the agreed workload is 5 in the plan column.

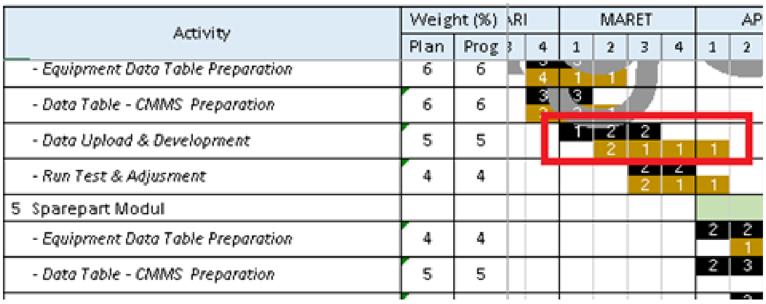

Figure 3. Workload

The black cell shows the planned workload for each task over time, while the brown cell shows the actual progress of a task or progress every week. From the red block in Figure 3, it can be seen that the progress of data upload and development tasks is in weeks 1, 2, 3 of March and early April. Planning is in weeks 1-3 of March. Although the actual work takes longer, the workload is in accordance with what was agreed at the beginning. The timeline may take longer, but overall it is on time.

2.1.2 Progress

Progress is part of the timeline in a project, the progress of project work is assessed from the actual workload obtained. Progress is obtained from the total progress every time a task is completed. Progress is the total of the daily task load of a task. The total progress in a timeline is expected not to exceed the load determined at the beginning. In the billing process, the progress timeline is always made its maximum value, which is the load value agreed upon at the beginning. Although actual progress can be greater than the agreed load value, if there is an agreement that the progress timeline can change according to the additional task load and the number of additional sub-tasks in the development process. In Figure 2 and 3 in CMMS, progress in a project uses weekly time, where each week can have different progress loads.

2.2 Computerized Maintenance Management System (CMMS)

Computerized Maintenance Management System (CMMS) is an application built to facilitate the maintenance team in the process of monitoring [1], [18], [19], managing, and maintaining assets in a company [3] and is part of Enterprise Resource Planning (ERP) in managing asset failure. The use of CMMS is more often used in the industrial world, although CMMS can be used in other fields such as health, transportation, and government. Basically, CMMS has features that can limit the use between a technician, planner, or manager, even an administrator. One important user is an applicant, who usually acts as this user who issues work orders to a technician to be forwarded to handling. While a manager is responsible for giving approval so that the work can be executed because it is feasible to do. While the planner is more focused on CMMS features related to preventive maintenance, where this feature is used to create a regular schedule to be worked on by technicians according to weekly, monthly or yearly schedules. As for the common features in CMMS.

2.2.1 CMMS Modules

Equipment or assets are the main features that must exist in a CMMS application, because the main concept of CMMS is to maintain assets [2]. All work request data will have a relation to an equipment module, such as the cost of spare parts consumption related to certain work, for example scheduled repairs, unscheduled repairs, damage, and others. Repair costs, work requests can be searched in this asset feature because of the asset relation to other features. [20] In the manufacturing industry, equipment is more inclined towards equipment that has high costs and is related to production equipment. Even now, equipment can be connected using IoT devices to get information related to certain sensors that indicate abnormal performance in a machine. To facilitate abnormalities in equipment or assets, there needs to be a check, maintenance or repair of an asset. To do this, a technician is needed to do the checking. This check requires a work order or work request from the related parties and has been approved by the interested party giving approval such as a manager, supervisor or team leader. Figure 4 shows the basic features of CMMS.

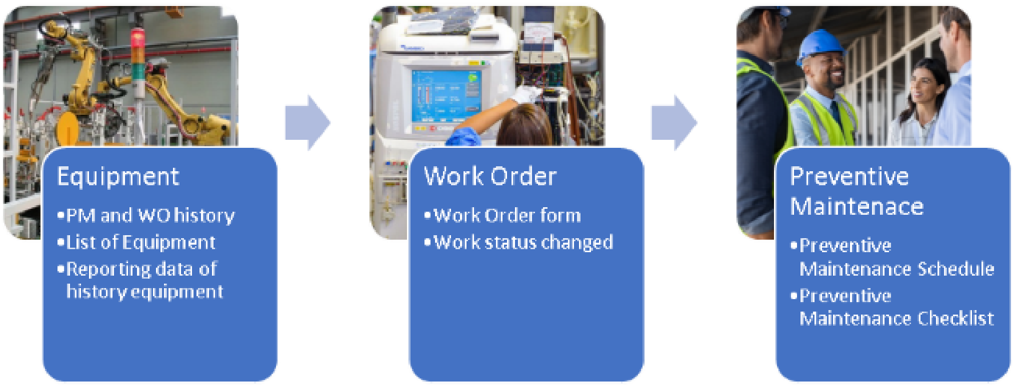

Figure 4. Basic CMMS Module or Feature

The basic features of CMMSin figures 4. As for the general stages of CMMS implementation in implementation in the manufacturing industry [21]

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2.2.1 CMMS Implementation Stages

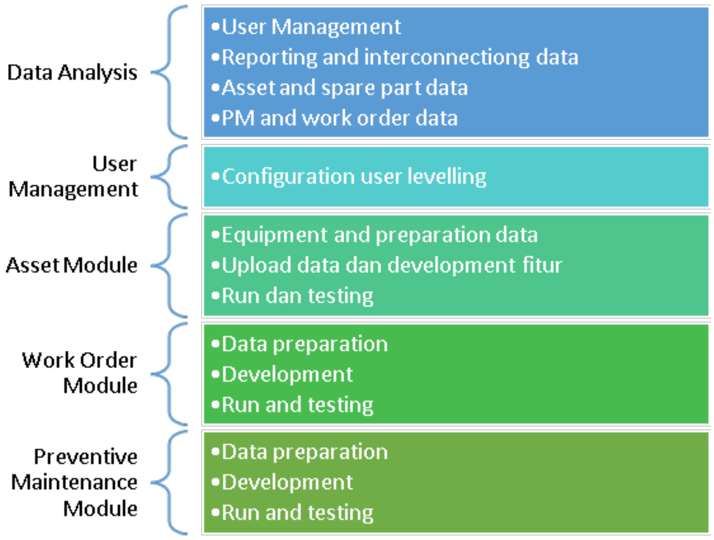

Figure 5. CMMS Implementation by GrX

In general, the CMMS implementation process at GrX in infrastructure companies can be seen in Figure 5 which consists of several stages, namely data analysis, user management, asset module, work order module, and scheduled maintenance module. And in each stage consists of several sub-stages that must be passed.

In data analysis, the most important thing is the process of preparing documents needed to support the application development process [22] . These documents are used to find out the details of the data displayed in CMMS features, especially in creating forms. This document will later become a reference for programmers and project managers in determining the flow of processes from CMMS, especially related to the next work order feature. While what needs to be considered in the development or implementation process of user management, assets, work orders, and preventive maintenance besides focusing on the implementation process of programming code, also how to preprocess data obtained from customers. Because not all data obtained from customers can be directly assisted to be entered into this CMMS database. But the GrX team will adjust the data obtained to match the template owned by GrX. And this is a part that takes time in the approval process of the CMMS project timeline.

2.3 K-Means

The K-Means algorithm is one method of clustering data [9], [23] , and it should be noted that clustering is different from the concept of classification. In the classification process, there is a determined target variable, while in data clustering it will cluster itself according to the similarity of data from a grouped group. The K-Means algorithm basically has the concept that a group of data will be shifted according to the data grouped based on the closest average value in a data. This K-Means algorithm has good accuracy if used in simple data, and not too much. And this is in accordance with the timeline data that does not have high complexity. As for the stages in the clustering process within this GrX CMMS, among others.

a. Determine the number of clusters from the CMMS development process in the manufacturing industry by determining efficient and less efficient clusters.
b. Determine the centroid of data in efficient and less efficient groups. The variable values of these two groups are based on the workload and progress of application development.

In Table 4, G.Centroid is the centroid value that has an efficient cluster, and B. Centroid has a less efficient cluster.

TABLE 4
EXAMPLE OF DATA CENTROID

No	Plan/Task	G. Centroid		B. Centroid	
		W	T	W	T
1	Data Analysis And Coordination	12	5	25	9
2	Implementation and Development User Management	12	5	25	9
3	Implementation and Development Asset Module	12	5	25	9
4	Implementation and Development Work Order Module	12	5	25	9
5	Implementation and Development Preventive Module	12	5	25	9
6	Implementation and Development Spare Part Module	12	5	25	9
7	Deployment (Go Live)	12	5	25	9

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8	Monitoring and Improving	12	5	25	9

The symbol W is weight while T is Time allocated as a weekly value. While the initial centroid value is in the good and bad centroid columns.

c. Next is to determine the closest cluster from a data. And to get a new centroid from the efficient and less efficient groups using the Euclidean distance formula.

$$d_{euclidean}(x,y) = \sqrt{\sum_i (xi - yi)^2} \qquad (1)$$

So, d is the Euclidean distance between the data point and the centroid, where x is the initial load or progress value and y is the determined centroid point. i indicates the i-th data of load or progress. And from Table 4, a new centroid value will be obtained by utilizing the formula.

Table 5 shows how to determine the closest cluster from two previously determined cluster groups, namely efficient and less efficient.

TABLE 5
FORMATION OF NEW CENTROIDS

Good - Centroid		Bad - Centroid		Tim.		C1 (Good)	
Weight	**Weeks**	**Weight**	**Weeks**	**Weight**	**Weeks**		
12	5	25	9	16	3	4.47	10.8
12	5	25	9	5	3	7.28	20.8
12	5	25	9	16	7	4.47	9.22
12	5	25	9	16	7	4.47	9.22
12	5	25	9	18	7	6.32	7.28
12	5	25	9	25	7	13.1	2.00
12	5	25	9	11	5	1.00	14.5
12	5	25	9	2	2	10.4	24.0

The new cluster is obtained by comparing two clusters C1 and C2. If the value of C1 < C2 then the new cluster value is efficient (good), if not then the value obtained is less efficient (bad).

d. In Table 6 are the results of determining the closest cluster from two previously determined cluster groups, namely efficient and less efficient. The new cluster is obtained by comparing two clusters C1 and C2. If the value of C1 < C2 then the new cluster value is efficient (good), if not then the value obtained is less efficient (bad).

TABLE 6
CLUSTER DETERMINATION

C1 (Good)	C2 (Bad)	CLUSTER 1
4.47	10.82	Good
7.28	20.88	Good
4.47	9.22	Good
4.47	9.22	Good
6.32	7.28	Good
13.15	2.00	Bad
1.00	14.56	Good
10.44	24.04	Good

e. After getting a new cluster, the next step is to update the new centroid value using formula (2)

$$NewCentroid = \sum \frac{ai}{n} \qquad (2)$$

where a is the total value of the overall efficient or inefficient cluster while n is the number of efficient or inefficient cluster

TABLE 7
NEW CENTROID

Tim.		New Good - Centroid		New Bad - Centroid	
Weight	Weeks	Weight	Weeks	Weight	Weeks
16	3	12	5	25	7
5	3	12	5	25	7
16	7	12	5	25	7
16	7	12	5	25	7
18	7	12	5	25	7
25	7	12	5	25	7
11	5	12	5	25	7
2	2	12	5	25	7

f. Based on formula 2, a new centroid value can be obtained for the efficient and less efficient task load and progress, pay attention to the data sequence in Table 4 which has a continuation in Table 6 in determining the

cluster of each stage and Table 7 which shows the data results of forming a new cluster centroid, where they are in sequence. The
way to centroid (good) for the load is by getting $\frac{\Sigma_{weight} 1-5\ AND\ 7-8}{COUNT(1-5\ AND\ 7-8)}$, what is meant by
1-5 and 7-8 can be seen in Table 4 which is the numbering of design stages other than the implementation and development stages of the spare part module. Likewise for the new
centroid part of progress (week) for efficient clusters $\frac{\Sigma_{weeks} 1-5\ AND\ 7-8}{COUNT(1-5\ AND\ 7-8)}$, where 1-5 and
7-8 are stages found in Table 4 other than the same stage process as progress calculation, namely implementation and development of spare part modules. This also applies to calculating new centroids for less efficient clusters. For less efficient cluster centroid
weigh $\frac{\Sigma_{weight} 6}{COUNT\ 6}$, while for a new centroid for a new cluster it can use the formula $\frac{\Sigma_{weeks} 6}{COUNT\ 6}$
, where 6 is a less efficient stage in the first loop of cluster search found in the implementation and development stages of spare parts. Table 7 shows the results of a new centroid.

g. After getting a new centroid, repeat the calculation of points c-f. Until there is no change in the results of the next cluster. So that the results of a new cluster from stage table 4 become a cluster shown in table 8.

TABLE 8
RESULTS OF CLUSTER FORMATION AFTER LOOPING

CLUSTER 1	CLUSTER 2
Good	Good
Good	Good
Good	Good
Good	Good
Good	Good
Bad	Bad
Good	Good
Good	Good

h. And from Table 8, a loop is performed so that the next cluster is obtained, namely cluster 2, if compared to cluster 1 there is no change. So for the next, no need to do looping again. In K-Means, looping stops until a new stable cluster is obtained or there is no change in the next loop.

2.3.1 Centroid

A centroid is the center point of a grouped data group [14]. If we group data into three groups, there will be three centroids, namely C1, C2, and C3. The value of this centroid will continue to change until no new data groups are found. In this study, from the GrX project schedule data, there are two new centroids for each iteration that show the efficient or less efficient development stage. This study uses the same development stages in several different projects.

2.3.2 Cluster

Cluster is a concept where several data groups or ecosystems have certain similarities. In an ecosystem, there may be several data groups. For example, in a box there are puzzles with various colors. If we are asked to group the puzzle according to its color, then we will get several data groups from the puzzle based on its color, such as red, white, green, and purple. Note that Table 9 is the workload and progress of several GrX team projects. From several stages that we process development from 4 projects, in Table 9 the project name is disguised using certain naming, then we will group the possible stages that need to be evaluated by grouping them into two groups, namely efficient and less efficient stages. These less efficient stages will later be evaluated with observation results using K-Means based on the workload and progress values of each stage.

III. RESULT AND DISCUSSION

This study has four projects that have the same stages but have different workload and progress values. Each stage will be analyzed using the K-Means method to obtain stages that need to be evaluated by the GrX team so that in the future cost adjustments can be made, both in terms of funds and the length of time it takes to work on subsequent projects. Table 9 shows the workload (W) and progress (T) of the four mentioned projects and will be grouped into efficient (G) or less efficient (B) stages.

TABLE 9
WORKLOAD AND PROGRESS OF EACH PROJECT

No	Plan/Task	Tim. W	Tim. T	G/B	Lix. W	Lix. T	G/B
1	Data Analysis And Coordination	16	3	G/B	15	8	G/B
2	Implementation and Development User Management	5	3	G/B	3	4	G/B
3	Implementation and Development Asset Module	16	7	G/B	15	7	G/B
4	Implementation and Development Work Order Module	16	7	G/B	21	6	G/B
5	Implementation and Development Preventive Module	18	7	G/B	21	6	G/B
6	Implementation and Development Spare Part Module	25	7	G/B	18	9	G/B
7	Deployment (Go Live)	11	5	G/B	4	8	G/B
8	Monitoring and Improving	2	2	G/B	2	2	G/B
No	**Plan/Task**	**Akb. W**	**Akb. T**	**G/B**	**Mn. W**	**Mn. T**	**G/B**
1	Data Analysis And Coordination	5	5	G/B	17	4	G/B
2	Implementation and Development User Management	5	3	G/B	6	2	G/B
3	Implementation and Development Asset Module	19	5	G/B	15	6	G/B
4	Implementation and Development Work Order Module	18	5	G/B	21	9	G/B
5	Implementation and Development Preventive Module	18	5	G/B	17	9	G/B
6	Implementation and Development Spare Part Module	19	5	G/B	9	6	G/B
7	Deployment (Go Live)	4	2	G/B	3	1	G/B
8	Monitoring and Improving	1	1	G/B	2	2	G/B

By using the K-Means stages, each project is calculated to get the cluster inclination at each stage. As for the graph in figures 6,7,8,9,10, the X axis is the workload value while the Y axis is the progress value. Note that Figure 6 shows one of the clustering graphs in the Tim project. In Table 10, the Tim project iteration process ends on the second iteration and in Figure 6 we see that the graph produced by this project is more inclined towards the CMMS development stage which can be said to be efficient.

TABLE 10
TOTAL LOOPING FORMATION OF NEW CLUSTERS

Number of Iteration			
Tim.	Lix.	Akb.	Mn.
2	4	3	3

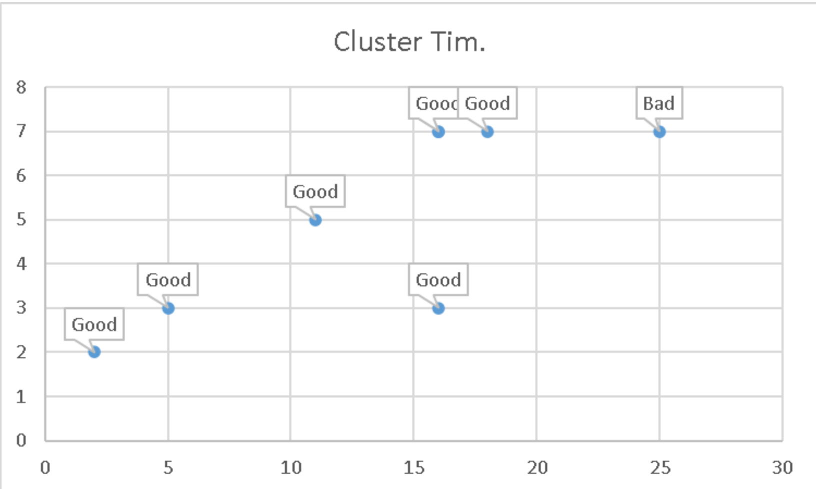

Figure 6. Tim project cluster.

And in the graph of the development process in the Tim project, between workload and work duration are directly proportional, meaning that these two variables will affect the cluster value of the development stage if they experience a decrease or increase in value.

Whereas in Figure 7, Lix project, each stage of the development process has 3 efficient clusters while there are 5 less efficient clusters.

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Figure 7. Lix project cluster.

Most of the stages that are in the less efficient cluster are in the implementation section. If viewed in terms of workload in Table 9, failure occurs when the workload is very high and the specified progress completion is too short or half the workload in determining the planning timeline. This failure could be due to the actual completion of the implementation process taking too long, and this needs to be analyzed again what caused it, based on existing data whether from the user or developer side. So that it can be overcome in the future, to get the most influential thing so that the development process takes too long with a high workload.
Like Lix project, in Figure 8 Akb project is also mostly in less efficient clusters at implementation stages. Even though the implementation stage is a major stage in the software development process. If you look at the workload in Table 9, this stage is indeed less efficient in its scheduling, with a high workload and a relatively short deadline.

Figure 8. Akb project cluster.

Compare with data analysis and coordination stages with low workloads but long work times have similarities with implementation stages. So there needs to be an improvement in scheduling that must be adjusted to its workload. So between workload and work duration must be balanced. While to achieve balance, further research is needed regarding balance between workload and time.
Unlike other projects, on figure 9 this Mn project most of the stages that are in less efficient clusters are located at stages other than implementation processes.

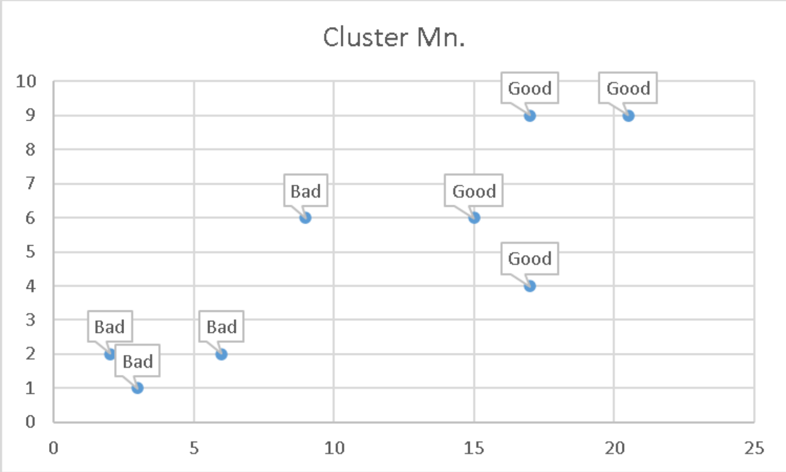

Figure 9. Mn project cluster.

Where failed implementation stages only exist on spare part module implementation. Based on workload and time variables in Table 9, it can be seen that efficient clusters at CMMS development and implementation stages have a ratio of approximately 2:1 between workload and time. So that what can be done for the future so that project stages are said to be in an efficient cluster is by looking at the workload from development being 2x larger than the time used. Looking at project stages that get efficient results.

In addition to analyzing each project, we can also analyze the overall project, namely from the four projects by determining the centroid value of the overall project. The results are shown in Figure 10. From the overall project in general, based on the previous statement that most of the less efficient stages in the CMMS development process are located at the implementation stage where the main focus is related to the implementation of asset, work order, preventive, and spare part modules. In addition, the implementation stage that becomes the focus when looking at workload and work duration, failure does occur when work duration has a value of more than 2x from workload.

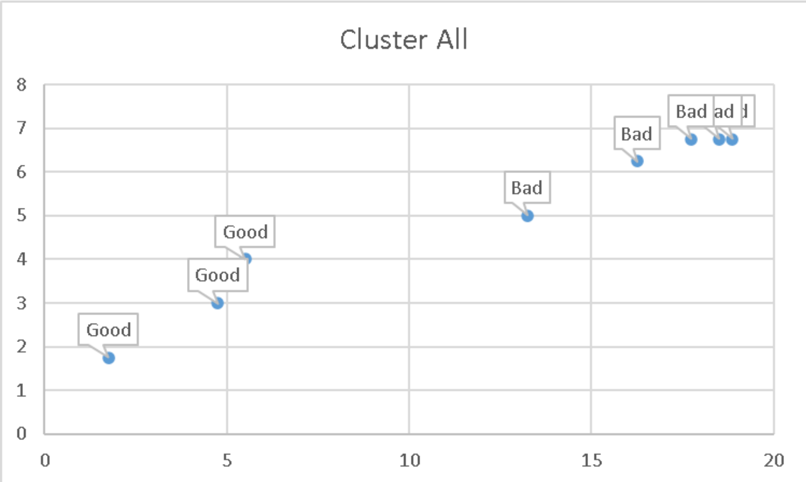

Figure 10. Overall project cluster

This can be seen when looking at workload and time required for each stage that is in a less efficient cluster. Based on the analysis process above, several perspectives or summaries were obtained regarding clustering at the GrX team's CMMS project stage.

From a general point of view in Table 11, implementation or development of CMMS application projects by the GRX team in completing each stage is still less efficient.

TABLE 11
SUMMARY

No	Plan/Task	Cluster K-Means Gen. Looping : 4			Tim. Looping : 2			Lix. Looping : 4		
		W	T	C	W	T	C	W	T	C
1	Data Analysis And Coordination	13.3	5	B	16	3	G	15	8	B
2	Implementation and Development User Management	4.8	3	G	5	3	G	3	4	G
3	Implementation and Development Asset Module	16.3	6.3	B	16	7	G	15	7	B
4	Implementation and Development Work Order Module	18.9	6.8	B	16	7	G	21	6	B

5	Implementation and Development Preventive Module	18.5	6.8	B	18	7	G	21	6	B
6	Implementation and Development Spare Part Module	17.8	6.8	B	25	7	B	18	9	B
7	Deployment (Go Live)	5.5	4.0	G	11	5	G	4	8	G
8	Monitoring and Improving	1.8	1.8	G	2	2	G	2	2	G
No	**Plan/Task**	**Cluster K-Means**								
		Akb. Looping : 3			**Mn. Looping : 3**					
		W	**T**	**C**	**W**	**T**	**C**			
1	Data Analysis And Coordination	5	5	G	17	4	G			
2	Implementation and Development User Management	5	3	G	6	2	B			
3	Implementation and Development Asset Module	19	5	B	15	6	G			
4	Implementation and Development Work Order Module	18	5	B	20.5	9	G			
5	Implementation and Development Preventive Module	18	5	B	17	9	G			
6	Implementation and Development Spare Part Module	19	5	B	9	6	B			
7	Deployment (Go Live)	4	2	G	3	1	B			
8	Monitoring and Improving	1	1	G	2	2	B			
	Bad	15.8	5.0							
	Good	3.3	4.0							

This can be seen from the results of the All column which shows that out of 8 stages only 5 stages have good or smooth work processes, while 3 other stages are less efficient. However, what becomes the focus is that the stages that experience less efficient implementation are located in the implementation process other than User Management. Looking at the weight contained in stages 1 and 4-6 in Table 11 in general, high workload values and relatively short work time determination result in this stage still needing improvement in the implementation process in subsequent projects and becoming a major consideration for improvement towards things related to implementation and development processes. If we look at workload and work duration on general stages that fail, it shows that for workload stages that are less efficient have a larger value than efficient stages, as well as work duration where failed stage values have larger values compared to efficient stages. And Based on workload and work duration in general, CMMS development is directly proportional between workload and work duration. So the main focus in future improvement processes so that CMMS development becomes smoother and is considered efficient is that there must be a change in process in data analysis and coordination with users as well as at the implementation and development stage on asset module parts, work orders, preventive maintenance, and spare parts.

Next, from the perspective of the four projects from the GX team, namely in the Tim, Lix, Akb, and Mn projects, the best implementation process is in the Tim project in Table 9 or Table 11. This can be seen from the 8 stages passed, there are 7 stages that have efficient clusters and only 1 stage that is in a less efficient cluster, and the cluster iteration process only requires 2 iteration processes. While in the Lix project, it can be said that most of the development processes are less efficient and need improvement in stages 1, 3-6. While in the Akb project, most of the development processes that are less efficient at important stages are at stages 3-6 as implementation stages. While in the Mn project, most of the implementation stages are good except for stages 2 and 6 which have development processes. To clarify whether a project stage affects the efficient or less efficient development process, further research is needed because here it only focuses on each stage. While to find out if there is a relationship between workload and work duration on its influence on the development process considered efficient or less efficient, it needs to be tested further so that this research has full strength to be used as a reference in the next CMMS development process.

From a stage perspective from all projects, the best development process has a level of results that approaches the target. This is achieved during user management implementation, deployment, monitoring, and improvement. This is evidenced by the best development results in 3 projects: Tim, Lix, and Akb. These three projects have similar clusters in general. However, other projects tend to have less efficient development processes, although some have good stages. For example, at stage 1 (data analysis and coordination), some projects have efficient clusters, but overall they are less efficient. To achieve an efficient cluster, it may require the best results from all four projects. Based on overall cluster results, GRX team implementation in CMMS projects needs improvement in data analysis and coordination, asset implementation, work orders, preventive and spare parts to improve CMMS development effectiveness in future projects. It also needs to be considered whether there is a relationship between workload and job duration in determining clusters. This needs to be tested in other studies and the use of workload variables can be divided into planned and actual workload. This can affect cluster value accuracy.

IV. CONCLUSION

This study provides a comprehensive analysis of four projects using the K-Means method to evaluate stages that need improvement by the GrX team. The results indicate that each project, namely Tim, Lix, Akb, and Mnk, has its unique challenges in achieving efficiency in the CMMS software development process. The Tim project leans more towards efficient CMMS development stages, while the Lix and Akb projects are mostly in less efficient clusters at the implementation stages. The Mnk project, on the other hand, has stages in less efficient clusters located at stages other than implementation processes. The findings of this study have significant implications for the future. The GRX team can use these insights to improve efficiency in the CMMS software development process. Specifically, the "data analysis and coordination" stage and the "asset module implementation, work order, preventive and spare part" stages need to be evaluated. The level of inefficiency, defined as when designing work time has a value lower than twice the workload, can be reduced by implementing the recommendations of this study.

Moreover, the study also opens up new avenues for further research. Future studies could explore the specific factors contributing to the inefficiency in the implementation stages of the Lix and Akb projects. Similarly, the factors causing inefficiency in stages other than implementation processes in the Mnk project could be investigated. This would provide a more nuanced understanding of the challenges in CMMS software development and pave the way for the development of targeted strategies to enhance efficiency. In conclusion, this study not only provides valuable insights into the current state of CMMS software development projects but also serves as a guide for future improvements. By addressing the identified inefficiencies, the GRX team can significantly enhance the efficiency of their CMMS software development process, ultimately leading to better outcomes for their clients.

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