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Designing and Implementing the Maintenance Measurement and Improvement System (Electricity Company as Case Study)

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Abstract: The purpose of this study is to design and implement the measurement and improvement system for maintenance that leads to improve and promote the maintenance conditions purposely in terms of organizational goals and strategies. In order to this, a model has been developed for realizing the research purpose based on the literature review and then the model has been implemented in the electricity company through the present organizational structure and the suggested team-based structure. This article seeks to express the steps of system designing and the results of its implementation. The main steps that have been conductedfor realizing the research purpose are determining the measures, determining the measurement periods, goal-setting, designing a measurement system, measuring and defining the corrective activities. Designing and implementing the measurement system and maintenance measurement and improvement result in the different outputs that some of them have been indicated in the following section.

- Considering the maintenance systems from different perspectives leads that not only technical aspect is attended, but also other aspects are considered.
- Reviewing and detonating the measures in different levels leads that the necessary and sufficient data are offered for the organization and the managers did not involve in this data that capture their decision making power.
- Measurement feedback and continuous monitoring help them in defining the corrective efforts for promoting the maintenance system.

Using the measurement feedback not only was effective in modifying the work processes, but also was effective in modifying some of the goals, policies and organizational structure.

Key words: Maintenance Measure · Improvement Mechanism · Maintenance Systems Evaluation

INTRODUCTION

Measure is a variable that is used for evaluating the conditions and sensitivities, comparing the places and conditions, evaluating the conditions and propensities in relation to the goals and objectives, supplying the warming information and predicting the conditions and the future trend.

The evaluation measures should have the characteristics of SMART system. This means that the measures should are specific, measureable, achievable, realistic and time frame. Different principles have been suggested for the systems evaluation measures that some of them were indicated in the following section [1,2].

- The performance measures should be branched from the organizations goal and are related to the organizations strategies.
- The performance measures should be selected through discussion among the involved participants such as customers, employees and managers.
- The non-financial performance measures should be considered and then selected.
- It is should be consideredthat the performance measures are different in the different conditions. In other words, a measure cannot beappropriate for all departments or organizations.
- This is important about the measures that changing the environment will results in the measures change.

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- The performance measures should be used simply and easily.
- The performance measures should offer rapid feedback.
- The performance measures should be designed so that lead to continuous improvement and do not attend only the supervision and control.

Several measures have been offered for monitoring the maintenance systems and also some studies have grouped these measures. But it is clear that the measurement should results in improvement and on the other hand leads to increase the systems costs.

In this study, a model has been developed for realizing the research purpose based on the literature review and then the model has been implemented in the electricity company through present organizational structure and the suggested team-based structure. The main steps that have been conductedfor realizing the research purpose are determining the measures, determining the measurement periods, setting the goal, designing a measurement system, measuring and defining the corrective activities.

Maintenance Measures and Their Structure (Research Framework): As indicated in the previous sections, measure refers to a variable that is used for evaluating the conditions and sensitivities, comparing the places and conditions, evaluating the conditions and propensities in relation to the goals and objectives, supplying the warming information and predicting the conditions and the future trend.

Different categories of maintenance performance measures/indicators can be identified from literature. The TPM concept [3] launched in the 1980's, provided a quantitative metric called OEE for measuring productivity of manufacturing equipment. It identifies and measures losses of important aspects of manufacturing namely availability, performance/ speed and quality rate. The OEE concept has become increasingly popular as a quantitative tool essential for measurement equipment performance in industries [4,5]. Arts and Mann use the time horizon to classify maintenance control and performance indicators into three levels namely strategic, tactical and operational[6]. Parida proposes a multi-criteria hierarchical framework for maintenance performance measurement [7] that consists of multi-criteria indicators for each level of management (i.e. strategic, tactical and operational). These multi-criteria indicators are categorized as equipment/process related (e.g. capacity utilization, OEE, availability, etc.), cost related (e.g. maintenance cost per unit production cost), maintenance task related (e.g. ratio of planned and total maintenance tasks), customer and employee satisfaction and health safety and environment.

Campbell classifies the commonly used measures of maintenance performance into three categories based on their focus [8]. These categories are: measures of equipment performance (e.g. availability, reliability, etc.), measures of cost performance (e.g. maintenance, labor and material cost) and measures of process performance (e.g. ratio of planned and unplanned work, schedule compliance, etc.).

Coetzee outlines four categories of maintenance performance measures with detailed indicators for each category [9]. These categories of indicators are:

- Maintenance results (measured by availability, MTTF, breakdown frequency, MTTR and production rate),
- Maintenance productivity (measured by manpower utilization, manpower efficiency and maintenance cost component over total production cost),
- Maintenance operational purposefulness (measured by scheduling intensity (scheduled tasks time over clocked time), breakdown intensity time (spent on breakdown over clocked time), breakdown severity (breakdown cost over total maintenance cost), work order turnover, schedule compliance and tasks backlog),
- Maintenance cost justification (measured by maintenance cost intensity (maintenance cost per unit production), stock turnover and maintenance cost over replacement value).

Ivara Corporation developed a framework of defining the key performance indicator for managing maintenance function based on the physical asset management requirements and asset reliability process [10]. They propose 26 key maintenance performance indicators and classify them into two broad categories of leading and lagging indicators. Leading indicators monitor if the tasks are being performed that will 'lead' to results (e.g. if the planning took place or if the scheduled work was completed on time) while lagging indicators monitor the results or outcomes that have been achieved (e.g. the number of equipment failures and down time).

Dwight [11,12] classifies performance measures into a hierarchy according to their implicit assumptions regarding the impact of the maintenance system on the business. He gives five levels in the hierarchy namely overt (visible) bottom-line impact (e.g. direct maintenance cost), profit-loss and visible cost impact performance (e.g. total failure/down time cost), instantaneous effectiveness

measures (e.g. availability, OEE), system audit approach (e.g. percentage of planned work and work backlogs) and time related performance measurement (e.g. life cycle costing and value based performance measurement).

In a study in Belgian industries [13], classified key performance indicators into two groups. First group called maintenance process/effort, is consist of leading indicators (work identification, work planning and scheduling, work execution). Second group called maintenance result is consist of lagging indicators (equipment effectiveness, maintenance cost effectiveness, safety and environment)

In a study [14] key performance indicators divided into four categories consist of efficiency, business and organization, timeliness and policy.

In a study [15], the authors develop a model. This model includes six perspectives:

- Innovation and growth(measured by Number of staff training, Staff productivity rate),
- Production (Availability, Performance, Quality, OEE, Planning Index, Total OEE),
- Maintenance (Schedule completion effectiveness, Staff efficiency ratio, Preventive maintenance efficiency ratio, Maintenance work efficiency, Equipment uptime, Backlog hours),
- Environment (Number of work accident),
- Costumer (Costumer's complain rate, Work lateness rate),
- Finance (Maintenance cost every period, Return on investment).

In this model Actual performance measurement is done through Analytic Hierarchy Process and Objective Matrix.

Maintenance Measures: Different measures have been developed for measuring the maintenance performance in the electricity industry that most of them examined these issues from technical perspective.

The most important measures that are used in the electricity industry were indicated in the following section.

- Failure rate or time: this refers to the frequency of emergency failures that occurred in a specific time.
- Repair time: the time that is needed to perform a specific corrective maintenance activity.
- Repair cost: this shows the maintenance costs based on the performed maintenances activities.
- Incidents frequency: this refers to the frequency of equipment failures that lead to salience.
- Manpower incidents frequency: the incidents that are occurred for manpower during repairtime.

Although these measures are applicable, but do not include all of the necessary cases that are needed for the suitable maintenance systems management. On the other hand, the systematic mechanism that result in target improvement do not observed for using the results of evaluating the present measures. Therefore, it is necessary to design a mechanism for defining, developing and collecting the necessary measures.

Necessity of the study (the importance of defining, developing and collecting the necessary measures and)

There are different policies and procedures for performing the maintenance activities and the technical reports of maintenance are current in the organizations based on them. Nevertheless, there are some problems and difficulties in the measures and the maintenance systems mechanism for improving that necessitate the present study. If the electricity companies' managers and experts can perceive that the maintenance systems are necessary because of high investments of the utilized facilities and equipment and also high social costs of salience and inappropriate quality of electricity energy, then they are able to examine such problems and difficulties. In the following section, some of the problems and difficulties were indicated.

- Necessity of defining the measures for every managerial level
- Necessity of designing a mechanism for examining the relationship between measures evaluation through defining the corrective activities separately for every modification in the maintenance process, modification in the maintenance goal and modification and review in the organizational goals.
- Necessity of the relationship between activities and goals of the maintenance with the organizational goal and strategies
- Necessity of considering all of the maintenance aspects more than technical aspect.

Designing Themeasurement and Improvement Mechanism: It is necessary to resolve the present systems problems, a mechanism is designed to measure, evaluate and finally improve the maintenance conditions. In the following section, the steps of this mechanism design were offered.

Measures Identification: The related measures for evaluating the systems efficiency and effectiveness are defined in this step. The measures type depends on the

type, activities and environment of the organization. So, the measures should be developed so that attends the improvement principle and also the ends do not replaced by the means. The measures should be determined based on the maintenance goals and these goals should be branched from the organizations macro goals and strategies.

The Organizations Macro Goals and Their Relationships with Maintenance: In this study, the strategic goals and the related measures were studied in four groups including financial, market-customer, processes and learning and growth so that their relationships with each other are recognized through discussion among the organizations senior managers and the maintenance experts.

The strategic goals in the financial group include increasing the income and resources and managing the capital budget. These goals in the market and customer group include increasing the customers' satisfaction and supplying the electricity energy timely. These goals in the processes group include improving the process performance, improving the equipment exploitation, improving the outsourcing and managing the project. Finally, the learning and growth goals include increasing the employees' productivity, developing the employees' competency, increasing the employees' motivations and satisfaction, promoting the internal communications and developing the learning and growth in the organization. Every strategic goal-setting can be conducted through the sessions among senior managers and the measures experts and users and finally these are confirmed by a strategic committee.

The customer satisfaction measure is located in the strategic goals of increasing the customers' satisfaction and the salience rate; production readiness, line readiness and substation readiness are located in the strategic goal of strategic process performance improvement and also are related to the processes and maintenance goals. It is resulted from the senior managers' different sessions that the maintenance performance improvement influences the measures. Therefore, it is necessary that the maintenance experts define this section so that their improvement leads to the higher measures improvement. In the following section, other measures of the maintenance were indicated.

The Maintenance Measures: The evaluation measures should have the SMART systems characteristics. This means that the measures should be specific, measurable, achievable, realistic and time frame.

Several principles were suggested to the evaluation systems measures that some of them were indicated in the following section.

- The performance measures should be branched from the organizations goal and are related to the organizations strategies.
- The performance measures should be selected through discussion among the involved participants such as customers, employees and managers.
- The non-financial performance measures should be considered and then selected.
- It is should be considered that the performance measures are different in the different conditions. In other words, a measure cannot be appropriate for all departments or organizations.
- This is important about the measures that changing the environment will results in the measures change.
- The performance measures should be used simply and easily.
- The performance measures should offer rapid feedback.
- The performance measures should be designed so that lead to continuous improvement and do not attend only the supervision and control.

As indicated, different measures were developed for evaluating the maintenance performance in the electricity energy industry that most of them attend the technical aspects. Because of this, the present study seeks to consider not only technical aspects, but also other aspects.

The suggested measures in this section, the important measures that are necessary to measure the maintenance systems efficiency and effectiveness were offered.

- Repair cost: this is financial measure that evaluates the extent of the costs that the organization spends in the maintenance areas. This cost includes the manpower and accessory costs and other related costs in terms of maintenance. This cost does not include the salience cost. This measure is measurable from a section level to the overall network level.
- Repair productivity: this measure refers to the maintenance cost and benefit. The maintenance costs that are allocatedto the Line and Substation and generally for overall network. This results in benefit for the organization through increasing electricity energy sale and decreasing the salience.

This measure is measurable through technical-economic calculations for different Line and Substations and for overall network.

- Budget percentage: this company is an organization that offers public service and has annual budget. This organization predicts its maintenance budget and the high rate of budget in this section indicates that the organizations appropriate performance in accordance with the performed plans and predictions.
- Accessibility: this is an important measure that refers the accessible (usable) time. This measure is the ratio of activity time to the sum time of equipment activity and stop [16], [17].
- Manpower incidents: this measure is an important indicator for the customers and employees that its monitoring shows safety in the maintenance activities.
- Repair frequency: this is in the section, equipment, line, substation and network levels that its measurement is a necessary function [17].
- Re-repair frequency: this measure refers to repletion in the maintenance activities and even sometimes leads to salience. This measure refers to this point that how the maintenance process performs appropriately [16], [17].
- Mean time to repair: the most applicable maintenance measure is the mean time to repair that refers mean time that is needed for a specific maintenance effort [16], [17].
- Mean preventive maintenance time: this includes performing the preventive maintenance efforts such as supervision, calibration and replacement that are designed desirably and appropriately. This has effective role in decreasing the sleeping time and the facilities and equipment maintenance and improvement [16], [17], [18].
- Sleeping time: this refers to the time that a machine is failure. In the other words, sleeping time refers to the time period that a machine starts to rework. This time includes perception, access, identification, provision, replacement, examination, experiment, logistic, regulation, management and bureaucracy times.
- Failure time or rate: this refers to the emergency failures frequency that occurred in a specific time [16], [17].
- Mean time between two repairs: this measure refers to the mean time between two continuous repairs that includes both emergency and preventive repairs.
- Mean time between two failures: this measure refers to the mean time between two failures.
- The network reliability: this is an effectiveness measure for maintenance. This is measurable through stop frequency or salience frequency [16,17].
- Knowledge frequency: it is possible to exploit the knowledge that is related to the maintenance employees through implementing a knowledge management system. This is useable for the organization.
- Recommendations frequency: this refers to the frequency of the recommendations that are confirmed and even implemented through suggestion system. This is a beneficial measure for evaluating the learning and growth aspects in the maintenance terms.
- Education time: implementing the effective educational periods lead to promote the maintenance employees' knowledge and also influence the maintenance process improvement.
- The conducted benchmarks frequency: frequency of the benchmarks that are related to the maintenance by other successful organizations will result in promoting the organizations conditions in terms of maintenance.

The Measures Structure: In this section, the measures structure was designed and offered based on the Balanced Scored Cards. This has four areas that include financial, customer and market, process and learning and growth [19].

In the financial area, the general financial measures and goals are described. In the maintenance effort, some measures such as repair cost, repair productivity and budget attraction percentage are monitored and evaluated.

In the customer area, the values of customers are targeted. Several values such as timely delivery, efficiency, communications type, image and other values are effective. The customer satisfaction measures also are considered in this section [19], [20]. In the repair issues, the measures such as network reliability, accessibility and the customer incidents frequency were considered.

In the process area, the effective crisis processes on the strategy are identified and the proper measures are recognized for measuring the process performance [20], [21]. It is necessary to identify the process so that the appropriate measures are designed for monitoring and controlling them. The important measures of this area include repair frequency, repletion in the repair frequency, mean time of repair, mean time between two repairs.

Table 1: The maintenance measures in the frame of balanced score card

Measures / Area					
Financial	Increase in the equipment productivity, repair cost-benefit		Repair cost	Budget percentage	Problem cost, reliability
Customer and market	Network reliability		System function time	customer incident frequency	Accessibility
	Salience frequency	Stop frequency			
Process			Repair time	Sleeping time	Repair incidents
	Repeated defects in repair	Repair frequency	Prevention / Emergency		
Learning and growth	Knowledge frequency		Maintenance suggestions frequency	Education time	Benchmarks frequency

In the learning and growth area, the effective intangible properties on the strategic success are recognized. The strategic goals of this area are selected based on the employees' competencies, human capitals, knowledge and technology and organizational culture [20], [21]. The measures such as the knowledge frequency, the maintenance suggestions frequency, education time and the benchmarks frequency are considered.

One of the factors that are ignored in the maintenance systems designing is attention to the managerial levels in offering maintenance measures. In the suggested mechanism for electricity industry, seven levels were designed for offering the measures. The measures user and their time period will be different based on that which mechanism is located in which level. Also some measures may are used in different levels for different goals. The defined levels in the electricity industry for classifying the maintenance measures include the following levels:

Section level: This includes all components of the every equipment.

Equipment Level: This includes the sections that do a specific activity and are defined as equipment. Preserving the measures information will be helpful for improving the maintenance process.

Substation and Line Level: It is necessary to preserve the maintenance measure information for every substation and line that the electric energy is transited for them. Also it is should be remembered that every substation and line includes several equipment.

Voltage Level: Every substation and line measures information that exists in every voltage (for example 63, 132, 230 and 400 voltage) is considered in this level.

Region Level: Every city is divided into different regions that this requires some regional measures are defined and monitored.

City Level: A city consists of the regions set that usually it is necessary to monitor every cities measure in the managerial levels.

Network Level: A province network consists of its cities. The performance measures in this level refer to the overall network efficiency and effectiveness from maintenance perspective.

Determining the Measures Evaluation Period: The measure without evaluation period is meaningless. Although some measures should be monitored in the short term, but others should be monitored in the long term time period. It is should considered in the measurement period definition that the period should be designed so that the measure evaluation leads to recognize the improvement or un-improvement and also provide the improvement opportunity. If there is not the improvement opportunity or the conditions are changed, the measure evaluation cannot satisfy the evaluation goal.

Goals setting whenthe maintenance system is successful and continues that consider the plan. The measures goals-setting in determined time periods requires the organization to think about the maintenance condition. Goal-setting must is a challenging function and also is not very ideal and inaccessible that promotes disappointing among the employees.

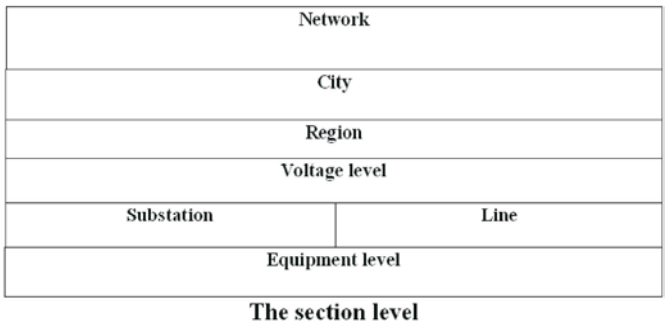

Fig. 1: The measures structure based on the report levels

One of the other characteristics of the measures goal-setting is the organizations flexibility so that it is possible to review the goals and predictions after conditions changing. Also goal-setting is performed by an expert group in the organization so that is rational, challenging and reasonable. The goal-setting team will be different based on the measure level, but it is an important that the short term measures should be designed based on the long term and strategic measures.

Evaluation Mechanism Designing: It is necessary to determine the evaluations time periods after defining the measures. Goal-setting needs a simple, efficient and effective mechanism for evaluation, monitor and improvement. It is necessary to design a suitable structure through determining the responsibilities and functions in order to this. Also it is necessary to design the forms and procedures and finally select the necessary instruments for appropriate performance.

The Structures, Forms and Procedures: It is necessary to design a structure that the responsible of the measurement and monitoring is determined in it and also the measures evaluation and their variances are identified through the standard forms and procedures in the frame of budget and time.

Instruments: These instruments refer to the evaluation instruments. It is obvious that different instruments should be designed and implemented based on the performance or inferential measures type. The performance measures should be exploited from the maintenance processes, but this is different about perceptions measures and it is necessary to exploit them from instruments such as questionnaire and interview. Also the individuals and groups perceptions that are important for the organization will be identified in this area.

The Performances, Perceptions and Variances Evaluation: It is necessary to evaluate the measures in the specific times and periods after designing a measures evaluation system. Also after evaluation in the specific time, it is necessary to compare the results of evaluations and the goals and if there is any variance, the solutions are offered. Indisputably, the evaluation will be performed through the instruments that have been designed previously. The evaluation and its responsibilities and territories were described in the previous section.

The Corrective Efforts: Every mechanismsfinal goalis implemented in this step. It is should be cleared in this step that which corrective efforts should be performed in terms of variances. In order to recognize the corrective efforts, the experts must identify the necessary efforts based on their measures such as criticality, organizational budget and other measures.

How to Design the Mechanism in the Main Organizational Structure: As indicated, the routine maintenance reports are implemented through formal structure. In this study more than formal structure, a structure that consists of teams for rationalizing the decisions about maintenance efforts is developed. This structure includes three different committees including incident, exploitation improvement and strategic committees.

- Constructing the incident committee for recognizing the causes of every incident, offering corrective efforts for preventing repletion in the similar incidents and how the conservative system performs. Firstly, it is should be remembered that an incident refers to the stops and saliences.These members are from the organizational assistances. The committee has a perfect technical identity and the technical issues are discussed in terms of maintenance.

The main functions of this committee includes the following cases:

- Recognizing every incidents cause (stop or salience) and offering the solutions for preventing its repetition.
- Examining the conservative performance in every incident and making the necessary decisions for improving the conservative systems performance.
- Constructing the improvement committee for making the policies and decisions in terms of the transition networks and equipment exploitation.
- The committee members include the senior manager and senior technical managers such as planning assistants, plan and development assistants and also technical managers. The main functions of this committee includes the following cases:
  - Offering the appropriate solutions and making decision about important transition network incidents and distribution (7 megawatt)
  - Making decision about the projects that need better and improvement exploitation.
  - Offering solutions for the transition equipment exploitation problems and difficulties
  - Examining the salience reports and making decision about the solutions of decreasing them
- Finally the strategic committee that decide about macro issues and organizational strategies. This committee also seeks to monitor the maintenance efforts effectiveness through their effects on the organizations strategic measures. As indicated, the maintenance activities influence the strategic salience measures, customer satisfaction, production readiness and substation and line readiness.
- This committee includes the organizations senior managers
- Procedure of the corrective efforts is so that the technical level maintenance measures are analyzed in the transition department level and exploitive assistance. The cases that need technical coordination with other departments are analyzed in the incident committee.
- The technical cases are effective in the comprehensive dimension than repairs and offered for senior manager and other technical assistances such as planning assistance and plan and development assistance. The cases that require coordination are examined in the improvement exploitation committee and its solutions are examined and also its corrective efforts are defined. The maintenance cases that influence the organizational macro measures are examined in the strategic committee. Indeed, the strategic committee evaluates the macro measures and the corrective efforts will be performed for maintenance activities in the cases that maintenance efforts result in the ineffective effects.

CONCLUSION

The appropriate maintenance measures development in the structure and in the accordance to the organizational macro strategies and improvement mechanism implementation will result in promoting the maintenance conditions. On the other hand, attending all of the maintenance components from financial, customer, process and learning and growth perspectives result in the systems promotion in the equilibrium manner. Some of the results of the mechanism implementation in the electricity company are indicated in the following section:

- Considering the maintenance from different perspectives leads that other aspect than technical aspect was attended. Offering the measures that show the maintenance effectiveness and also targeting these measures values based on the organizational macro measures lead that the senior organizational managers attend this section, because the effects of maintenance performance on the organizational activities becomes more tangible.
- Reviewing the measures and segmenting them in different levels lead that the sufficient and necessary data is provided for the organizations managers and also the managers do not involved in the different information and measures that capture their decision making power. For example, some measures did not calculated before this study, while the measures are the most important measures that show the maintenance systems effectiveness. Additionally, these help the managers in the implementation step to apply the necessary strategies in terms of repair methods based on the equipment life period.
- The measures evaluation feedback and their monitoring result in defining the corrective efforts for promoting the system. For example, “mean time of sleep” measure was not proper for inaccessible region and this leads to increase the salience. Examining the measure condition in the different time periods indicated that the main cause of this is the long period of access. It was cleared after examining these problems solutions that using geographic information system can leads to improve the

measure. Because there were necessary facilities of the geographic information system in the organization, they were used for identifying the precise problem place and the equipment regions. Then they were used to recognize the nearest path for accessing them and mean time of salience was decreased in the next periods.

- Using the measures evaluation feedback not only modify the work processes, but also is effective in modifying some goals, policies and even organizational structure. After examining different measures especially the process-oriented measures and their analysis in the improvement committee. It was suggested the substation and line repairs are performed in two independent groups because of their specialization and they performed under technical manager's supervision.

The mechanism that was designed in this study can be implemented and utilized in every organization. The important point is that the defined measures importance was consideredequally in the mechanism in our study. Also which measures should be concentrated that has more importance and weight for the organization. Therefore, it is suggested that the importance and weight of every measure is recognized in the future studies. These measures weights should be recognized through studying their importance in the organization and considering the senior managers and the maintenance experts' viewpoints. Also it is necessary to review the measures in every time periods because of their change and evolution.

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