ABSTRACT

Title of Document:	A STRUCTURED METHODOLOGY FOR IDENTIFYING PERFORMANCE METRICS AND MONITORING MAINTENANCE EFFECTIVENESS
	Maria Mercedes Amoedo, Master's, 2005
Directed By:	Professor Mohammad Modarres Department of Mechanical Engineering Reliability Engineering Program

Most current maintenance programs focus on achieving the main goals of maintenance operations: increasing mean time between failures, reducing time to repair and minimizing costs. Some researchers have focused on optimizing these variables. Detailed analyses have been conducted in the fields of equipment wellness, spares administration, planned maintenance and structured organization. Still, many organizations fail to fulfill today's ambitious objective of guaranteeing operations while achieving high reliability and maintaining safety. A comprehensive method of maintenance assessment that considers key factors and indicators that influence the main goals of maintenance is still sought after.

This paper discusses a new approach to performance-based maintenance management. The objective is to determine an integrated reliability management system that provides a method of aligning maintenance operations with the business strategy and monitoring performance of key technical, human and organization goals over time.

A STRUCTURED METHODOLOGY FOR IDENTIFYING PERFORMANCE METRICS AND MONITORING MAINTENANCE EFFECTIVENESS

By

Maria Mercedes Amoedo

Thesis submitted to the Faculty of the Graduate School of the
University of Maryland, College Park, in partial fulfillment
of the requirements for the degree of
Master of Science
2005

Advisory Committee:

Professor Mohammad Modarres, Chair
Professor Ali Mosleh
Professor Joseph Bernstein

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Acknowledgements

I would like to thank the Ford Argentina Stamping and Body Maintenance staff for providing valuable information to this research. I specially thank Mr. Osvaldo Lerose for his helpful feedback on the trees development.

I am also grateful to my parents that always helped me achieve my ambitions and my husband Jan whose unconditional support has always been the foundation to my career and academic success.

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List of Acronyms

AHP: Analytic Hierarchy Process

BTS: Built To Schedule

CMMS: Computerized Maintenance Management System

CSI: Customer Satisfaction Index

DFM: Design F or Maintainability

FMECA: Failure Mode and Effect Criticality Analysis

FTT: First Time Through

GT: Goal Tree

GTA: Goal Tree Analysis

MSI: Maintenance Satisfaction Index

MTBF: Mean Time Between Failures

MTTR: Mean Time To Repair

OEE: Overall Equipment Effectiveness

PM: Preventive Maintenance

RCM: Reliability Centered Maintenance

TPM: Total Productive Maintenance

VF: Visual Factory

WG: Work Group

WO: Work Order

Chapter 1: Background

Over the past hundred years maintenance management had to rapidly change to keep pace with the increase of complexity in manufacturing processes. In the beginning, equipment maintenance was reduced to optimize the corrective activities in order to minimize downtime. Good performance was dictated by the ability to reduce time to repair. Therefore, the main focus was put on improving human technical skills as well as troubleshooting effectiveness.

When reactive maintenance was organized in such a way that failures were immediately found and solved, the need for availability improvement led to preventing failures to occur. The concept of preventive maintenance changes the way of managing maintenance. The objective moves from reactive to proactive maintenance. This means staying ahead of the problem through programmed inspections to find potential failures and eliminate them before they manifest.

Different preventive maintenance programs have been implemented. Initially, fixed schedules were developed. These methods did not consider the equipment usage pattern. Consequently, frequent interventions in low utilization equipment represented a waste of resources, while failures still occurred in equipment with higher utilization.

In order to develop a customized plan a more careful analysis was needed. This analysis should define the optimum maintenance schedule for each equipment. With customized planning, resources were allocated more efficiently. This led to significant cost reduction and availability improvement.

The significant increase in competitive products generated the need to reduce costs and increase quality and reliability. Old techniques were no longer suitable in the new continuous improvement era. One of the initiatives that arose was the Total Productive Maintenance (TPM) [1].

TPM has the objective to prevent failures and quality defects, minimize equipment losses and improve equipment cycle life. The active participation of every part of the organization is the key ingredient for TPM success. Consequently, production personnel participate by conducting inspections and minor interventions on their own equipment. This self-directed maintenance helps detecting equipment malfunctioning in an early stage and provides with important information to maintenance department. Additionally, maintenance force can be assigned to more critical tasks now that minor repairs are handled by production personnel.

This innovative approach to maintenance management was a breakthrough. Still, there was a sustained increase in automation and therefore the need for more skilled technicians to ensure equipment performance. Clearly, organizational goals included the reduction of product indirect costs and in most cases hiring was unaffordable so new alternatives in maintenance operations had to be studied.

The most recent advances in maintenance management include Design for Maintainability (DFM)[2] and Reliability Centered Maintenance (RCM)[2]. DFM is a proactive approach that aims at reducing the frequency of required repairs, the time to repair and the amount of preventive maintenance interventions. The goal of Design for Maintainability is maintenance prevention.

RCM started from the aeronautical industry. Thorough analysis conducted on a group of aircrafts under different maintenance schedules concluded that increasing the frequency of inspection does not necessarily reduce the number of failures. On the contrary, after overhaul the aircrafts would show an increase in the probability of failure due to infant mortality. Additionally, it was found that most failures are related to random events such as poor maintenance practices, overload or improper equipment operation.

RCM methodology is based on choosing the most important systems and determining their potential functional failures. With the aid of Failure Mode and Effect Criticality Analysis (FMECA) the most critical causes of failure are identified and an appropriate maintenance plan is developed to control them. This approach admits the “run to failure” option for those equipment failures that will not represent a significant safety or economical concern on production.

The previous discussion shows that maintenance practices evolved to a focus oriented approach where resources are put were they are more needed. Still these initiatives are being implemented among many industries with different levels of success. Evidently, there are other factors making the results widely vary not always properly considered.

Success or failure in maintenance management depends on how technical, human and organizational factors are considered. This study will focus on how to integrate these factors and methodically define a set of performance indicators to monitor maintenance operations effectiveness.

Chapter 2: Methodology

2.1 Overview

The Balanced Scorecard concept [3] will be used to determine the maintenance strategies. This concept will help define the fundamental pillars upon which the overall maintenance operation rests. From these basic pillars, a group of attributes will be derived using a hierarchical decomposition such as the Goal Tree Analysis [4]. Successful implementation and monitoring of these few attributes will lead to more effective management of maintenance operations.

A set of metrics must be selected to lead the attributes implementation. These indicators need to monitor the maintenance strategies in such a way that any deviation from the objectives can be detected and immediately corrected.

The problem resides in that no attribute can be fully monitored by an isolated metric. As such, a set of indicators would be needed for this purpose. The assignment of each metric to an attribute must be determined through expert judgment. The Analytic Hierarchy Process (AHP) [5] is a powerful tool to formally bring expert judgment to define relevance and importance of each metric to the fulfillment of the attribute.

2.2 The Balanced Scorecard

The Balanced Scorecard is a management system that enables the organization to align their vision with the strategy and translate it into action. Its main purpose is to define a set of metrics that will closely monitor the organization performance. The structured methodology allows us to understand the key aspects in maintenance operations preventing the uncontrolled and unfocused selection of performance indicators [6].

In this thesis a model of the Balanced Scorecard has been developed in context of a complex manufacturing plant. The first step in developing the Balanced Scorecard is to define the vision of maintenance operations. This is defined as: **Attainment of high performance of people, equipment and processes in maintenance.** This ultimate goal is to be accomplished through a methodical strategy that must consider all different aspects of the organization. Therefore, the strategy will be decomposed into fundamental pillars.

When selecting the pillars, the first and basic aspect to consider is repairs management. Once a failure occurred the cause must be effectively found and solved. Therefore, the REACTIVE pillar goal must focus on reducing the downtime through minimizing the time to repair. In order to prevent failures to occur in the first place, the focus must change from a reactive to a proactive approach. The PROACTIVE pillar will aim at reducing the amount of failures through appropriate maintenance planning. The goal is to maximize the time between failures.

Having good reactive response and effective preventive maintenance (PM) plan is not sufficient without the necessary tools and spares. The LOGISTICS pillar must ensure resource administration including materials, equipment, spares and energy consumption. Therefore this fourth pillar goal is to guarantee resource availability with minimum cost. Even with good planning and having the necessary tools and spares, maintenance personnel must have the appropriate skills to do a quality job. The goal for the TRAINING pillar is to prepare personnel for their job requirements.

Finally, it is important to keep in mind that all maintenance related activities are planned, performed or controlled by individuals. Without personnel motivation maintenance results are in jeopardy. PEOPLE pillar is probably the most critical because it is present in all other pillars. Its goal is to increase personnel motivation and performance in order to get the best out of each employee.

Table 1 shows the scope of each pillar with its goal definition. Detailed analysis of each pillar will be discussed in the following section.

Table 1. Fundamental pillars of the strategy

PILLAR	SCOPE	GOAL
REACTIVE	Repair action after the failure occurs	Minimize time to repair
PROACTIVE	Planning and monitoring actions to prevent failures	Maximize time between failures
LOGISTICS	Tools, spares and equipment and their availability	Guarantee resources availability with minimum cost
TRAINING	Technical and interpersonal training	Prepare personnel for their job requirements
PEOPLE	Personnel involvement, human performance, safety and workforce planning	Get the best performance out of each employee

In order to fulfill the overall vision each of the five goals must be realized. It wll be considered that each pillar has the same relative importance with respect to the vision accomplishment.

2.3 Hierarchical Decomposition Using Goal Tree Analysis

The next step in the balanced scorecard definition is to translate the strategy into action. Goal Tree Analysis (GTA) [4] is the means used in this thesis to perform a hierarchical decomposition of each of the strategic goals. The purpose of the decomposition is to arrive to the lowest measurable function, whereby obtaining the fundamental attributes. In this way, each general goal can be easily managed through the analysis of this few attributes. This simplification is valid given that GTA carefully breaks down the high level goal into subsequent sub goals so that success of all sub goals will guarantee the main goal accomplishment.

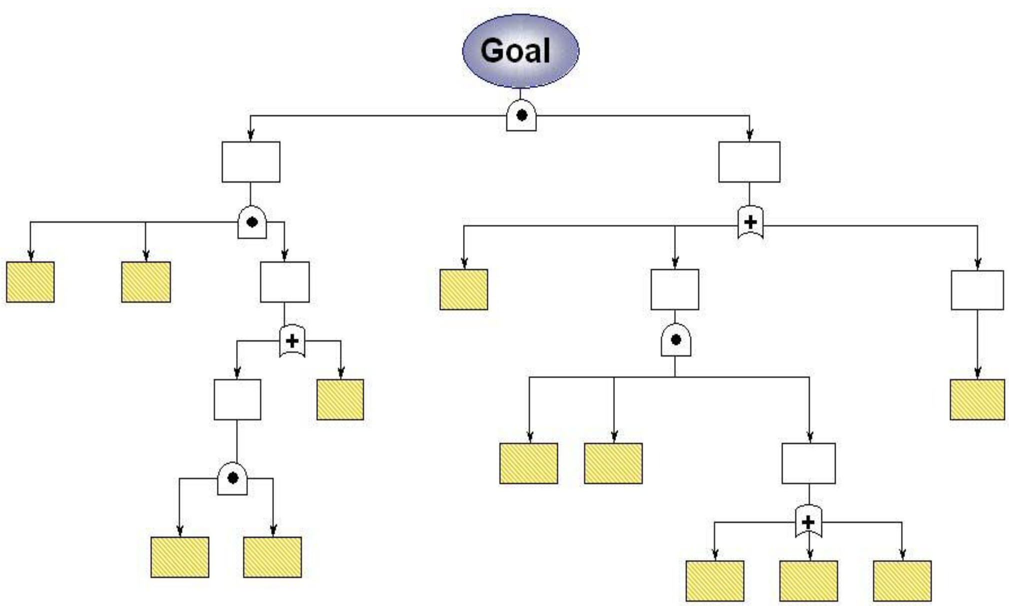

Figure 1. Goal tree hierarchy decomposition

It is important to mention that every subgoal can be eventually decomposed into lower level subgoals. The level of decomposition will be defined intuitively and will mainly depend on the degree to which the attribute can be measured. Therefore, paths that will result from the decomposition may vary in level depth.

Figure 1 shows a conceptual diagram of the goal tree (GT). The higher level represented by an oval is the ultimate goal which is decomposed in lower level subgoals until the lowest possible decomposition is met. The shaded blocks represent these fundamental attributes.

Note that logical connectors are used to show in which way the combination of various attributes will lead to the goal accomplishment [7]. The AND gate implies that all attributes must be satisfied in order to guarantee the goal success. On the other hand, OR gates indicate that the goal can be met if at least one of the success paths underneath is achieved. Considering this, we must refer to "alternatives" rather than subgoals given that not all the attributes need to be necessarily met to ensure success at a higher level.

The complete decomposition has been conducted considering maintenance operations and management literature and was also based on the authors' judgment. Figures 2 to Figure 6 in the following section show the GTs for each pillar.

2.4 GTA for the five strategic pillars

2.4.1 REACTIVE Pillar

Figure 2 shows the hierarchical decomposition for the REACTIVE pillar. There are two possible alternatives to manage a failure depending on the availability of an alternative process. These processes include, backup systems, redundancy, standby equipment and bypass procedures [8]. The OR gate shows that success of either path will lead to the top goal accomplishment.

The decision to launch the alternative process will be based on the repair time estimate, the time to switch from normal to alternate operation and the potential loss of production the alternative process represents. Therefore, good communication between maintenance and production personnel is essential to make the best decision. At the same time, clear procedure must be in place to perform a quick change over.

An important part of having an effective alternative process in place is its reliability. Stand by and redundant equipment must be in good condition when needed. Even though these installations are rarely used, it is important to have them under planned maintenance. Note that in order to have a good maintenance plan the REACTIVE goal must be satisfied. Figure 2 shows this dependency between REACTIVE and PROACTIVE GTs.

The repair path is followed when no alternative process is available or a decision to conduct the repair facing the down time is made. In this case a correct diagnosis followed by an effective repair action is needed.

Many variables must work together in order to perform a correct diagnosis. A complete and reliable monitoring system together with appropriate troubleshooting procedures will help detect the failure promptly. Additionally, the technician must have the appropriate knowledge through previous experience or training. As mentioned earlier, good performance also depends on personnel morale and therefore this subgoal will be repeatedly seen throughout the GT.

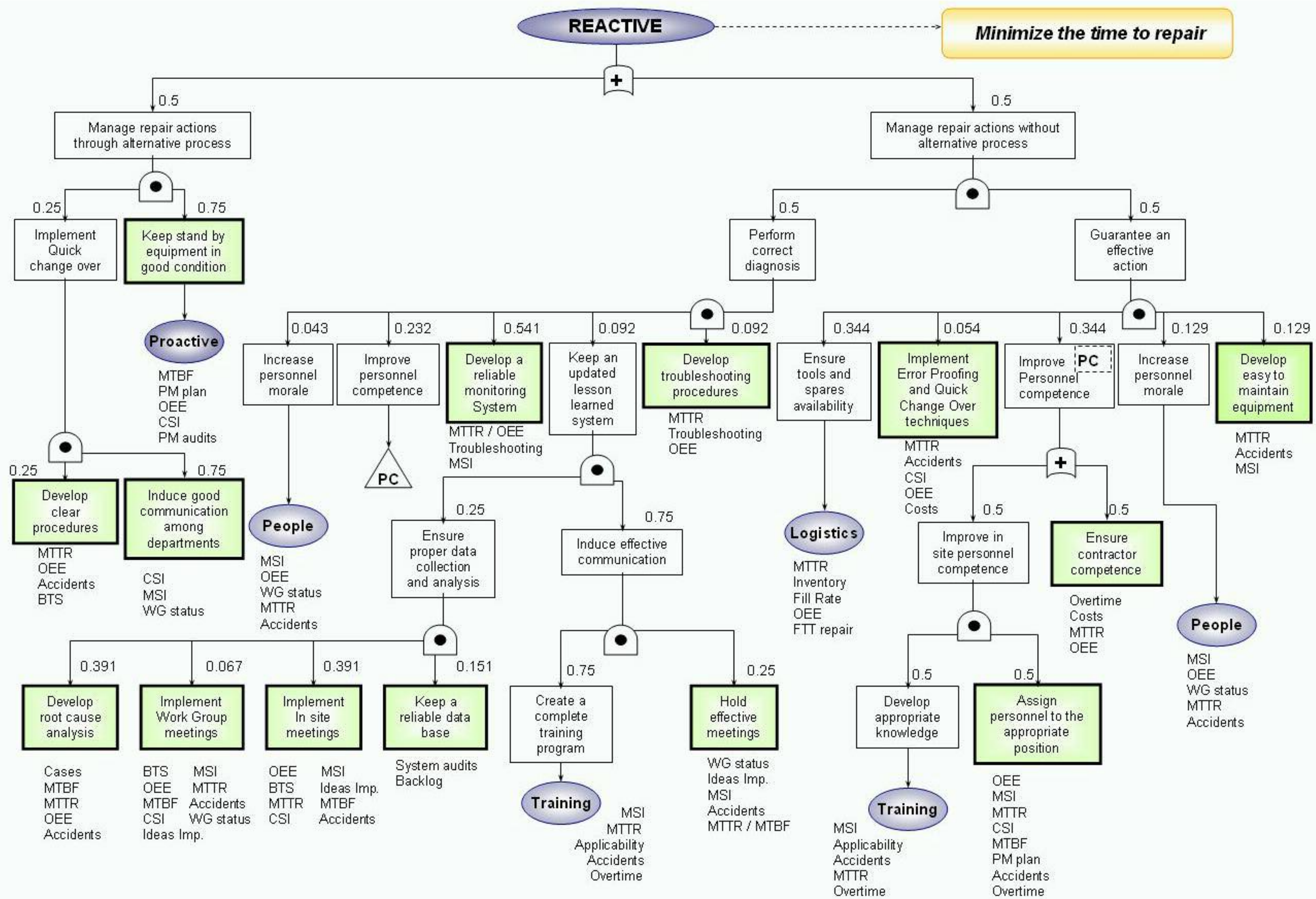

Figure 2. REACTIVE GT

Conducting an effective action mainly depends on the technician knowledge and skills. Still, having the ability to conduct the repair is not enough if the proper tools and materials are not available. And even with the skills and resources, the optimum repair action would be carried out if the equipment is easy to maintain. Hard to reach spaces will make the job more difficult, thus increasing the time to repair. Some design approaches such as design for maintainability [2] have this into consideration and provide error proof devices. Having these convenient tools already in the equipment and quick change over procedures can expedite the repair process.

The REACTIVE GT shows a detailed decomposition of these many goals in lower level attributes. Some of these attributes deserve a comment. Doc Palmer [8] emphasizes the importance of assigning personnel by skill. Those individuals that are prone to easily find a root cause and promptly implement a solution should be available for production support where time to repair is critical. Generally, these containment actions are highly effective but many lack of quality work given the nature of the repair. On the other hand, preventive and predictive activities should be conducted more carefully. For these interventions, troubleshooting ability is not required but skilled work with high quality finish is essential. Therefore, meticulous technicians should be assigned to planned maintenance tasks.

Another important aspect to consider is the work group activities. There are different kinds of meetings that will be explained in more detail when discussing the PEOPLE pillar. The importance of these meetings for the REACTIVE pillar is that they are a source of data analysis and lesson learned communication.

2.4.2 PROACTIVE Pillar

Figures 3a and 3b show the PROACTIVE pillar decomposition. All planned activities are considered including preventive, predictive and self-directed maintenance, programmed replacements and projects implementation. The latest refers to improvement modifications conducted with maintenance department budget.

Preventive, predictive and replacement programs are effective if there is a dynamic schedule, oriented to prevent the loss of the system function. This is the objective of Reliability Centered Maintenance (RCM)[2]. The plan must be routinely evaluated and adjusted based on failure history, condition-based techniques and root cause analysis among other reliability tools. This resource optimization needs appropriate data collection and analysis so having a reliable Computerized Maintenance Management System (CMMS) is essential. Similarly to most management tools, the critical part is not putting the system in place, but maintaining it up to date with all equipment information and analyzing this information routinely. Terry Wireman [9] reinforces the need to have a complete and accurate data in order to support maintenance decisions making process. Therefore, when implementing a CMMS it is important to design an easy to use system, promote personnel involvement and provide necessary resources such as computers and time to enter the data. Optimally, the CMMS will be integrated with other systems in the organization

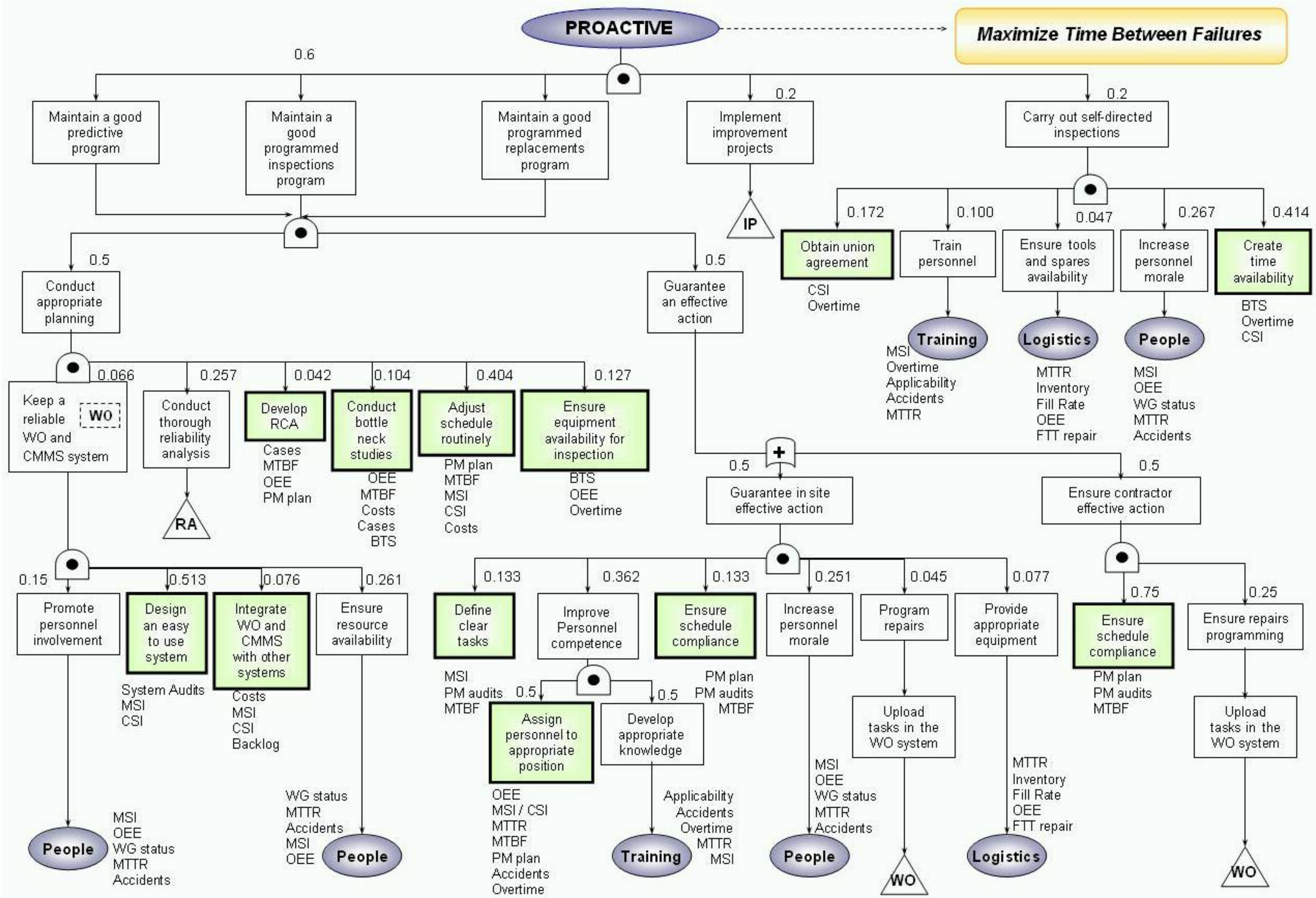

Figure 3a. PROACTIVE GT

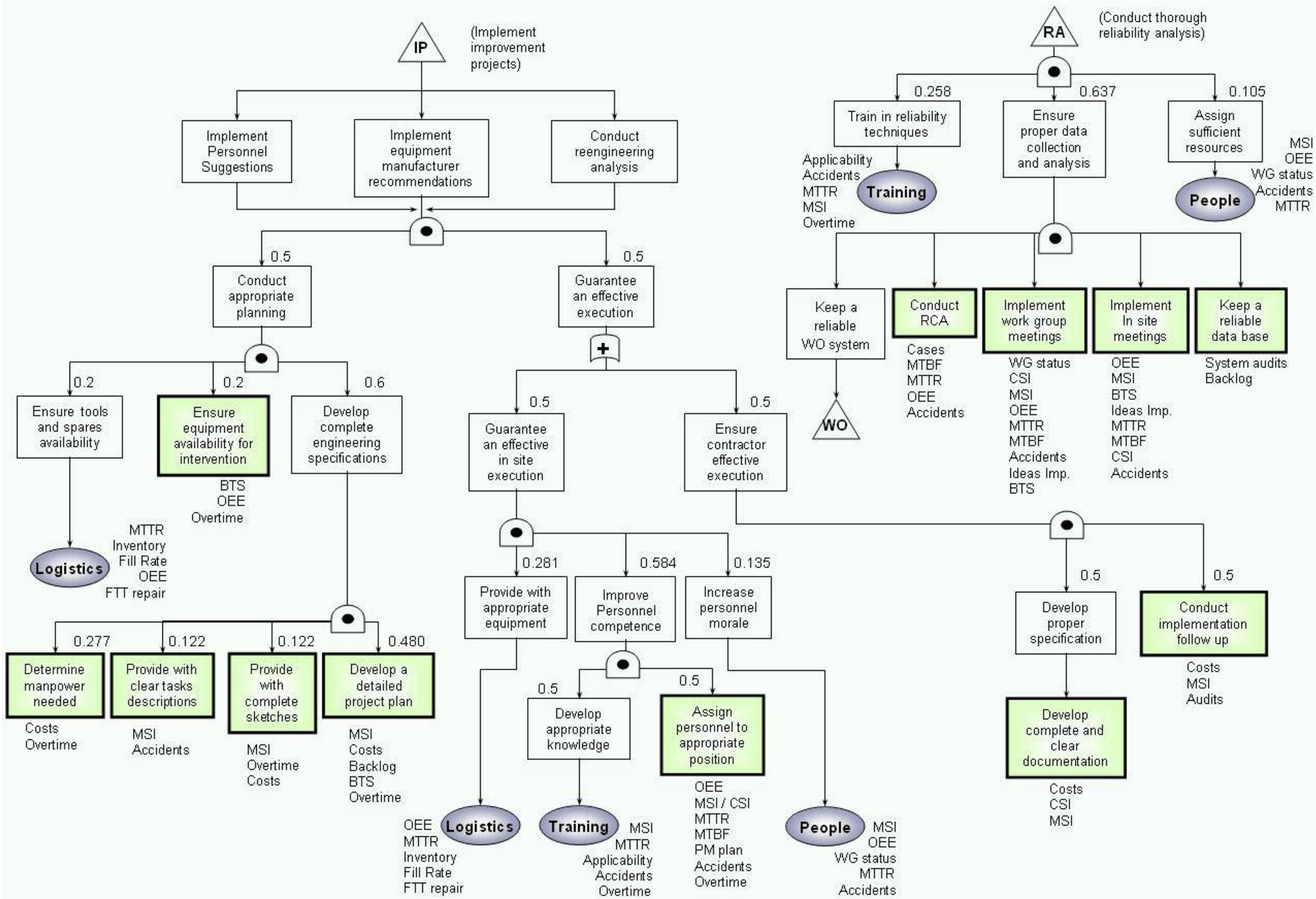

Figure 3b. PROACTIVE GT (Continue)

Planned interventions also need to consider equipment availability. This is especially important when production systems are in continuous operation. In many cases production patterns must be adjusted to support the PM down time. Planning ahead of time production department will ensure an effective intervention without significant production loss.

Preventive or predictive activities can be performed by the on site personnel or by a contractor. As discussed in the REACTIVE pillar, the quality of the intervention will depend on the technician skill and morale as well as having the appropriate tools and spares. Additionally, structured procedures must ensure the schedule compliance and also inspection tasks must be clearly defined. This includes not only what to inspect, but also what is considered substandard conditions. This is particularly important for predictive inspections where the variables analyzed increase as the equipments degrade and a threshold value will define the need for replacement.

Another important aspect in maintenance inspections is the repair scheduling. For processes that allow short periods of down time it is common to conduct the planned maintenance in two phases. First, the entire equipment is inspected following a detailed checklist. If a substandard condition is found, the technician must decide whether to repair it or program the repair in the near future. This decision will depend on the time needed to conduct the repair, the equipment availability and the tools and spares availability. If the repair is not conducted immediately, the task should be entered in the Work Order (WO) system. This is a very important part of the process that requires discipline. Without proper repair scheduling, the substandard condition can worsen significantly leading to equipment failure before the next PM inspection.

The improvement projects include personnel recommendations that can reduce the time to repair, increase the time between failures or reduce the risk of personal injury or property damage. Other projects are derived from manufacturer recommendations or process modifications. For all projects complete engineering specifications must be developed. Additionally, if the project implementation is to be conducted with maintenance workforce, detailed sketches and a list of resources (parts, tools, materials, and manpower) must be prepared. On the other hand, when contractors are involved the implementation plan must be closely followed in order to verify compliance with the specifications.

The third type of planned maintenance tasks are the inspections and minor repairs conducted by the operator. This self-directed maintenance approach provides the benefit of discovering equipment problems in an early stage. In order to commit production personnel to add this task to their routine there must be agreement from the union. This step is fundamental when implementing self-directed maintenance. Then, operators must be trained in the inspection checklists as well as in some basic skills to perform minor repairs.

An important aspect that is usually overlooked is that conducting daily inspections is time demanding, especially if subsequent interventions are required. Therefore, self-directed activities must be included in production planning. Considering these activities as part of the daily tasks will prevent loss of motivation and operators performance.

2.4.3 LOGISTICS Pillar

Figures 4a and 4b show the LOGISTICS GT. This pillar focuses mainly on materials, parts and tools availability but it also includes energy as a resource to be administrated. As mentioned earlier, the objective is to ensure resource availability with minimum cost. The latest is the actual challenge. Benjamin W. Niebel [10] defines one of his five primary pillars as “Cost Reduction” and parts and tools administration is one of many activities to fulfill this goal.

In the presented approach, LOGISTICS pillar goal will be accomplished by ensuring equipment, parts and tools availability, optimizing energy consumption and minimizing maintenance inventory. The first condition can be satisfied not only by guaranteeing the part is in stock, but also weather this part is available immediately. Having the part somewhere in a chaotic store will make the repair ineffective and increase the mean time to repair (MTTR). Therefore, great effort should be invested keeping a clear and properly identified storage area. This may include the development of equipment drawings / sketches and a reliable inventory system, as well as applying Visual Factory (VF) procedures. Lack of proper stores administration result in parts unavailability. If storages do not provide with the necessary parts, technicians would start keeping basic spares at hand leading to personal storages generation .

Nevertheless, the concept of personal storages should not always be rejected. For large installations where distances are important it would be wise to have materials

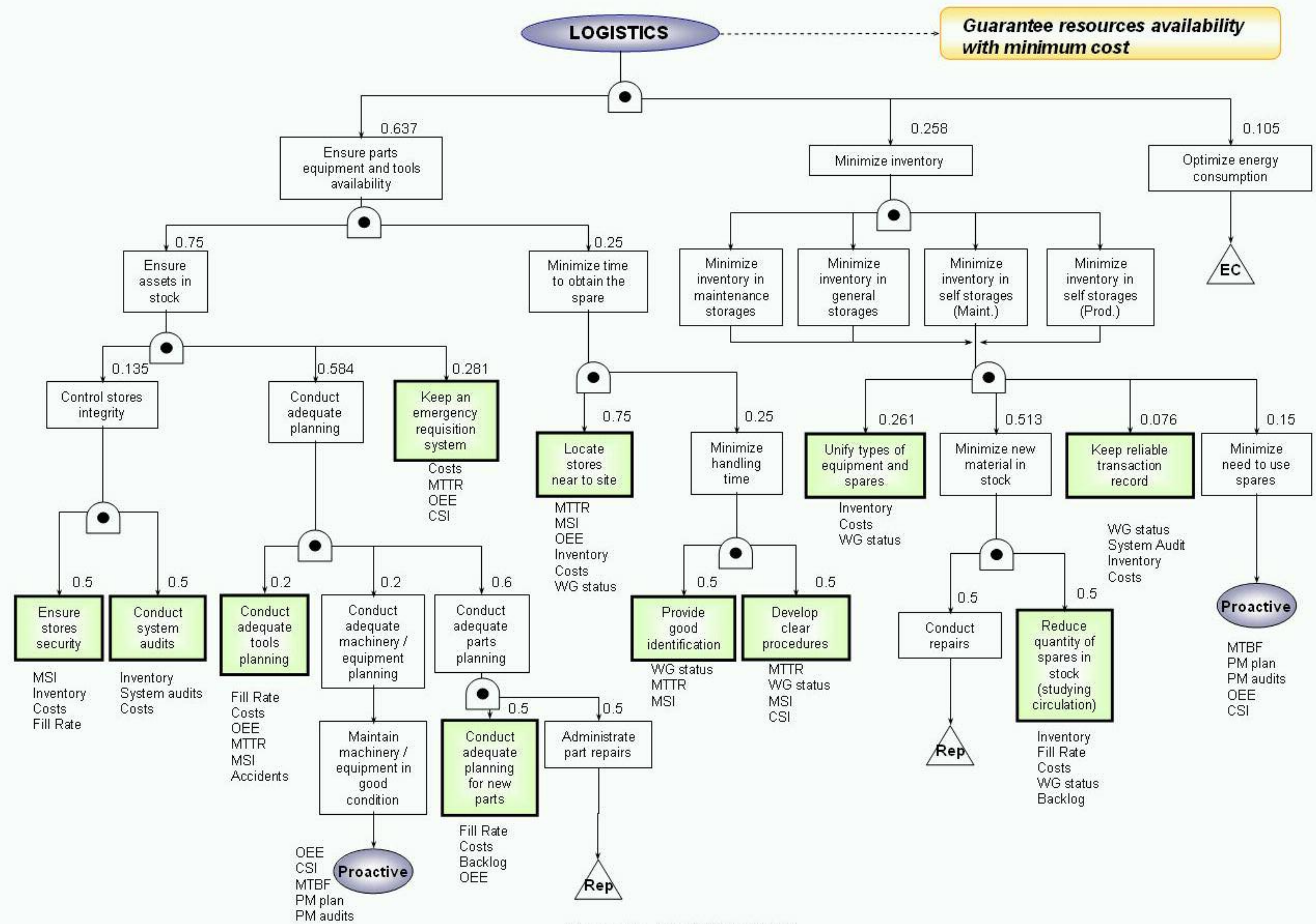

Figure 4a. LOGISTICS GT

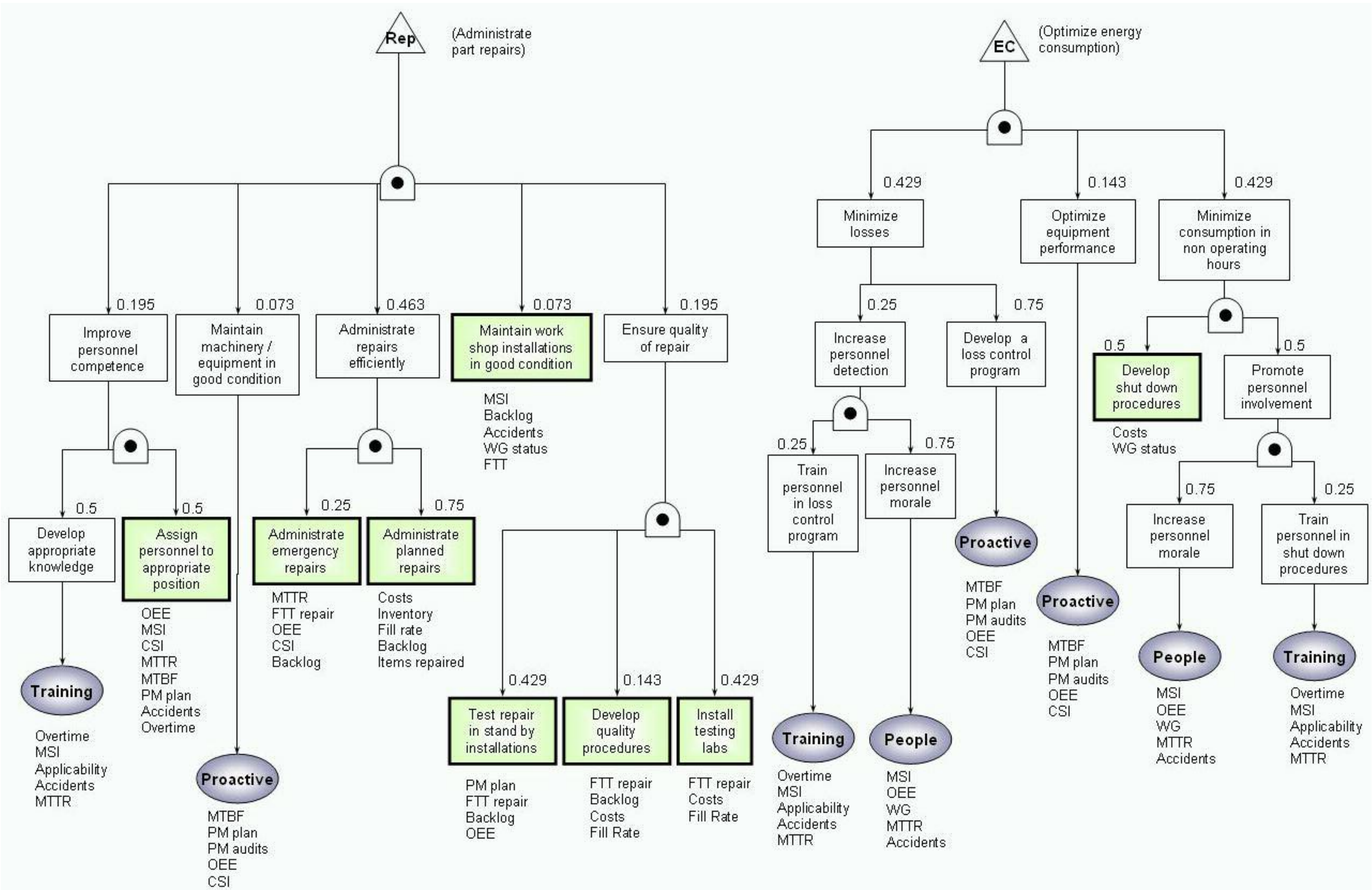

Figure 4b. LOGISTICS GT (Continue)

near to site. But parts and their quantity must be carefully selected to prevent high inventory. Materials with high circulation and low cost are prone to be in the self-storages. Additionally, spares specified for one particular equipment can also be stored near to site.

Even though having parts at hand may significantly reduce the time to repair, multiple storage places may be complex to maintain and control. The lack of organization is a menace for parts administration and it is the main cause of inventory multiplication and high maintenance costs. Therefore, proper analysis of advantages and disadvantages is needed when making the decision to have multiple storage places.

In order to ensure the part is in stock when needed, it is essential to conduct adequate planning. Basically, this includes the part list derived from a close analysis conducted in the early design and installation phases. Additionally, one interesting approach that Niebel reinforces is having a parts salvage program [10]. By repairing malfunctioning parts the cost of inventory decreases since a new part is not required. In order to implement a salvage program there must be workshops with the appropriate equipment, sufficient technical skills and clear procedures for repair administration and repair quality assurance. Clearly, the repair would worth the investment if the total repair cost is less than the actual cost of the new part. It is important to notice that the total repair cost not only refers to manpower, parts and materials but there are also hidden costs that usually exceed these tangible values such as opportunity costs. For example, it may take considerable time, skills and resources to repair a failed servomotor from a welding robot. The repair cost can easily surpass the cost of a new servomotor. But if this spare part is not in stock and the arrival time takes weeks, the down time cost generated may be unacceptable given the significant production loss.

Planned repairs can represent a great benefit, but it can also increase failure risk considering that the repair does not always leave the part “as good as new”. Therefore good quality procedures that include testing of the repair of parts must be established. Once the part is certified it can enter the storages and become part of the inventory.

But spare parts are one of the three resources that must be administrated. Other important assets that should be controlled are tools and special equipment. Some examples of special equipment include measurement and test equipment, notebooks used for PLC and SLC program access or portable welders. Generally, these types of equipment are expensive and maintenance department own a few. Therefore they deserve special control of their uses and storage. Additionally, they must be under PM schedule.

Now that parts, tools and equipment availability was discussed, focus must be on the inventory reduction. It was mentioned that repairing faulty parts helps reduce the amount of parts in stock. Another way to minimize the inventory is by studying parts circulation (for example, how many electrodes are used per week). For this purpose the equipment history must be studied in detail. With this information and the spare acquisition time, a minimum limit is set for that particular part so that when reaching that value a purchase order must be filled.

An important cause of high inventory is the multiple types of equipment and vendors. This is common for facilities in expansion where new systems are installed and old equipments are improved. Equipment form vendors that are not certified by the company will certainly have parts list that greatly differs from those that are already specified. Therefore, parts with identical specification but from different suppliers will be duplicated in maintenance stores. Having a list of selected and certified vendors will help minimize this spare parts multiplication reducing the inventory.

The final condition for reducing the spare costs is minimizing the need to use them. Well maintained installations will have higher performance and lower failure probability. Consequently the need to replace a defective part will be minimized through proper planned maintenance.

As mentioned before, energy consumption will also be treated as a resource to be optimized. This goal will be attained by minimizing energy losses, improving the equipment performance and reducing energy consumption in non operating hours. Some sources of energy loss are water leakage from defective pipe lines, air loss from pneumatic devices, unnecessary power consumption for stand by equipment, etc. One approach for loss control is conducting regular inspections under the preventive maintenance schedule. It is also helpful to have personnel involved in loss detection and reporting.

Regarding the non operating hours, a detailed study needs to be conducted to identify the equipment that need to be continuously energized and those that can be powered down. Once the list of equipment to be powered down is defined, clear shut down procedures must be established per equipment.

2.4.4 TRAINING Pillar

Training is a highly important activity that is usually underestimated. The general believe is that time spent for training is time lost, given that many courses are ineffective and after some weeks the student would probably forget what he was taught. The problem is that this statement is generally true because of the lack of proper planning. Training must be a "just in time" activity. This means that the person should receive the course when he or she would get the best out of it. Figure 5 shows that training planning should consider the right course for the person. For this purpose, a tool known as training matrix is used. This matrix will relate each employee with the skills and training needed for their job positions. Having defined the matrix, a customized training plan is easily constructed considering not only the courses applicable to the position, but also the adequate level according to the employee's expertise.

Training courses are grouped in four different categories: knowledge base, on the job training, attitudinal and lessons learned. On the job training focuses on skills and tasks directly related to the person's daily activities. Generally, these courses are taught by more experienced co-workers and are carried out in site. This type of training is especially applicable for new employees or when the person is assigned to a new position.

Lessons learned courses are designed to expand individual experiences to the rest of the workforce. The objective is to prevent errors experienced in one application to occur in another one as well as share the best practices among the department.

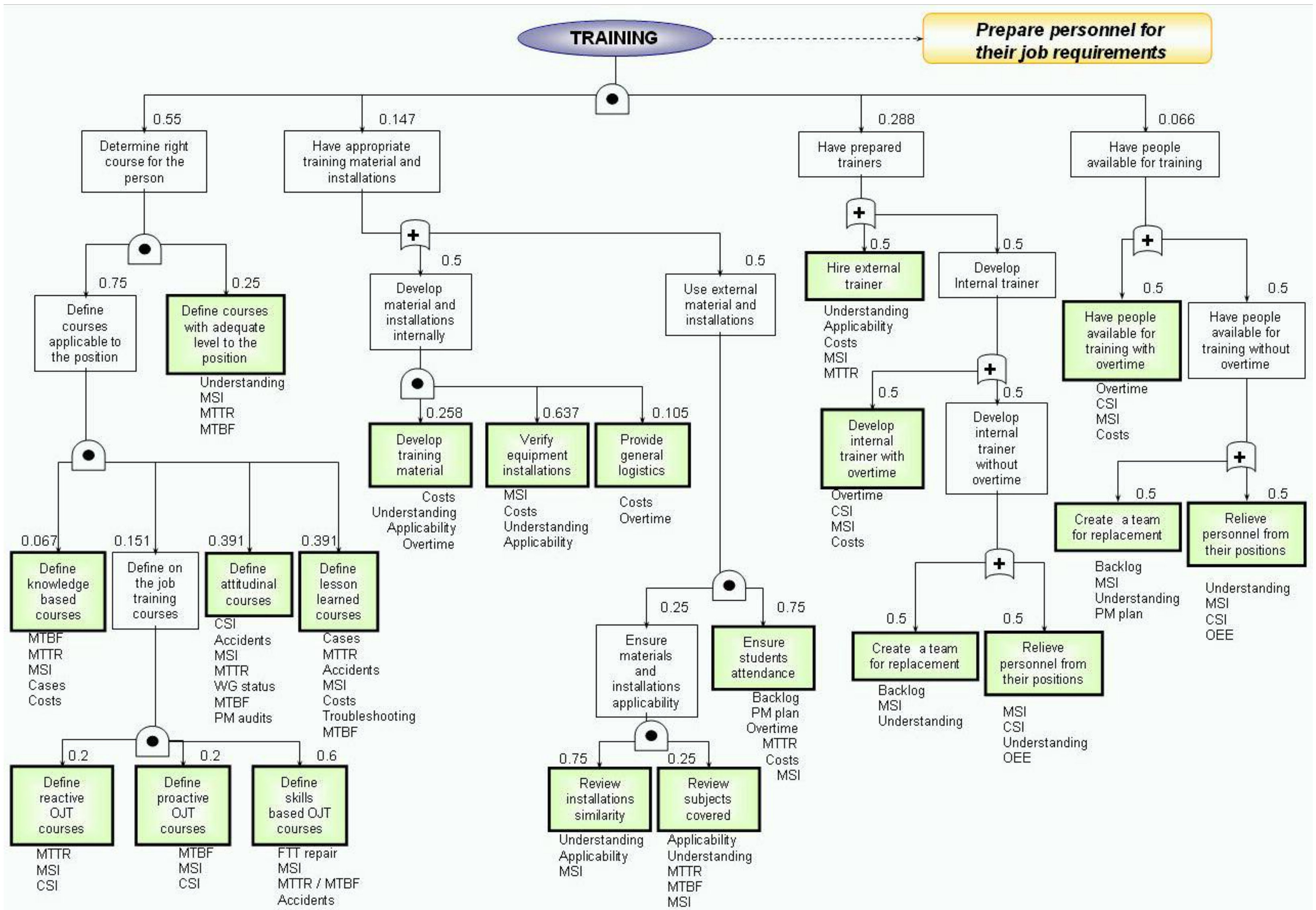

Figure 5. TRAINING GT

Together with the course definition, there must be material preparation and people organization. The course can be prepared within the organization or it can be outsourced. There are advantages and disadvantages in both approaches. Internally designed courses are generally more applicable to the organization needs given that they are customized. But a lot of effort is demanded to prepare the material and installation and usually lack of quality and proper learning methods. On the other hand, external courses are designed by qualified training groups. Additionally, given that many agencies and most manufacturers provide with a set of courses for different customers, they already have the materials and installations ready to use so the course is available immediately. Yet, these courses not always fit the organization particular needs, are less applicable and many times useless. Another disadvantage of external course is that when there are budget cuts, the organization cannot afford contracting external training. Moreover, considering that it is common that the students must attend classes off site overtime is a must which is usually unaffordable in times of recess.

These conditions discussed are considered in Figure 5. A similar approach is made when selecting the trainer. Most maintenance management literature reinforces the value of developing interpersonal training. For these cases having internal trainers is the most effective. Proper planning is needed to take the person away from the operation to prepare him as a trainer. For this purpose some maintenance departments have a special team for replacement. These technicians will normally be assigned to improvement tasks such as spare parts repair, equipment testing or projects implementation and will cover the person to be trained up when needed. This same methodology can be seen for “have people available for training” subgoal.

2.4.5 PEOPLE Pillar

As discussed in the previous sections, people morale is a critical aspect that affects most attributes. PEOPLE pillar focuses on getting the best out of every employee. The way to achieve this goal is depicted in Figures 6a and 6b. The first sub goal is to increase employee’s motivation. R.F. Pagano[11] indicates that a person is mainly concerned about self-esteem, independence, self-actualization, and recognition. From this perspective, defining challenging objectives is an important aspect for self-esteem. Additionally, good communication of these objectives as well as departamental and organizational objectives is essential to make the employee understand and become part of the company’s vision. But sharing the goals with the employees will make no difference if there is not an established recognition plan that would reward the individual that actively participates in the results improvement.

Independence and self-actualization are two parameters that must be analized when assigning roles and responsabilities. Individuals that are overqualified for their job position will find it difficult to learn something new leading to loss of motivation. But if they are underqulified, they will feel frustrated also leading to motivation problems. In conclusion, the supervisor must ensure that the person is comfortable in his position.

Last but not least, there ust be a propert benefits and compensation plan that would be suitable for each employee’s experience and expectations. The program must be aligned with the employee development plan.

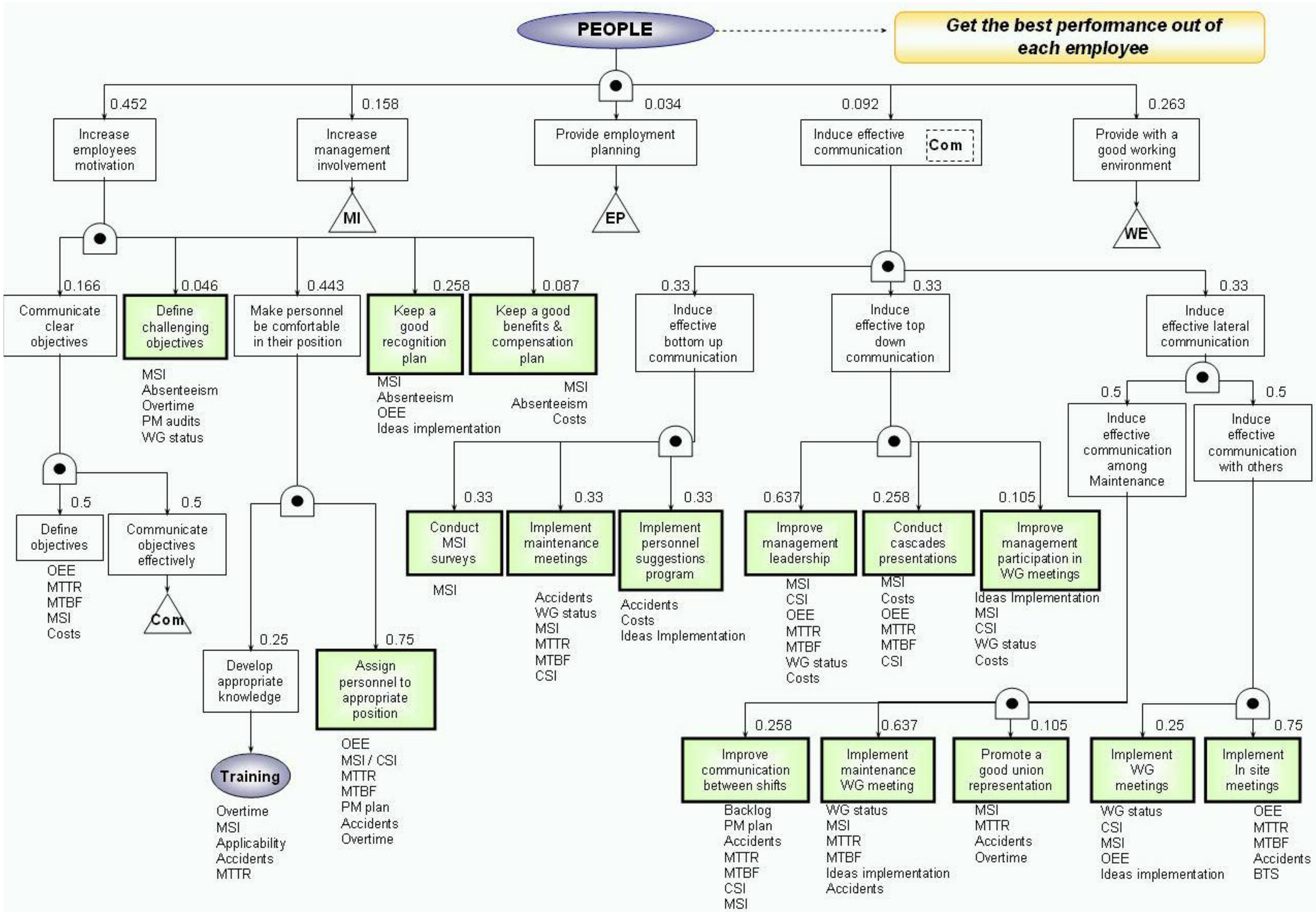

Figure 6a. PEOPLE GT

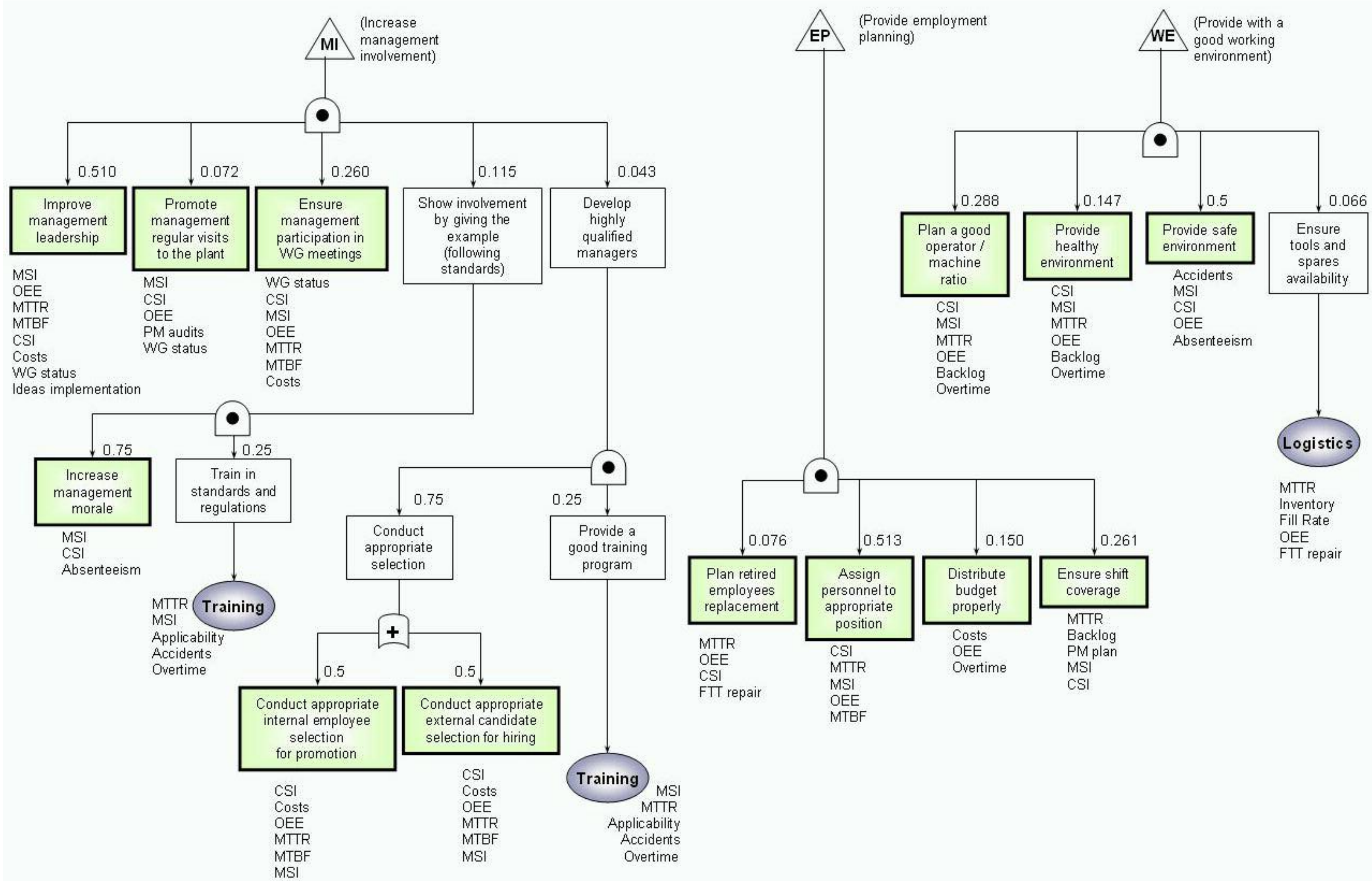

Figure 6b. PEOPLE GT (Continue)

Another sub goal in the PEOPLE GT is increase management involvement Note that the term involvement was chosen instead of commitment. Managers can be fully committed to the Organization's objectives but they need to communicate this commitment to his subordinates in a clear and consistent way. To be consistent, they must give the example by following the standards and procedures established. Also, managers must actively participate in work group meetings. They must understand what the team's needs are and offer support in order for them to succeed. Additionally, it is important for people to realize that the manager and other supervisors are concerned about day to day activities, so it is important to promote regular visits of managers to the plant. In addition to employees increased motivation, plant touring would allow the managers to get in touch with real problems that are being experienced.

The last item in management involvement is to develop highly qualified managers. A proper selection needs to be done from the very beginning, based on the applicant experience and leadership skills. The person to be assigned to this position can be either promoted or hired. Either way, a thorough training program must be provided to enhance technical and personal skills.

Employment planning is another activity to consider. It was already mentioned the importance of assigning each employee to the appropriate position. Another important task is to distribute the personnel in order to ensure shift coverage. This is a complex analysis that must balance the need for reactive maintenance technicians in the productive shift with a group of serviceman that will work on pending work orders and the proactive team that will perform preventive and predictive activities.

The fact that people will retire some day is commonly neglected. Given that these people are generally highly experienced employees their separation from the organization generates an important knowledge drain. To prevent this situation, an early plan must be developed to prepare new employees for the future vacant position.

Based on the previous parameters, the human resources budget should be assigned properly. For example, most organizations have a higher compensation for people that work the night shift. Imagine that the night shift will perform the preventive and predictive tasks. If the strategy is to have 70% of the workforce in proactive activities, therefore this percentage of technicians will be in the night shift. Therefore, enough budget must be assigned to cover the excess of salary compensation for night shift personnel.

When discussing motivation it was mentioned the need of proper objectives communication. Communication is a primary subgoal of the PEOPLE pillar decomposition and that is why the “Communicate objectives effectively” attribute is addressed to “Induce effective communication” subgoal. Communication must be established bottom up, top down and also laterally. This means that superiors must communicate with their subordinates as well as subordinates need a means to communicate with their superiors. Additionally, communication among co-workers must also be excelled.

Work group activities are a good environment to share opinions and discuss problems as well as are suitable to cascade high level objectives. That is why it is essential that these teams are conformed by cross-functional individuals as well as different hierarchies. Three types of meetings are considered. Work group meetings refer to cellular manufacturing teams. These meetings are usually held on a weekly basis. Most participants are from production department with one or two representatives from the supportive areas (maintenance and logistics). People from other areas of interest such as safety, quality or manufacturing are requested to participate if needed. These meeting are always programmed since operations must be stopped in order to gather all the production team. Therefore they have a specific agenda that includes different issues of the area performance (volume, quality, ergonomics, safety, down time, etc.)

The second type of meeting is the in site meeting. These are held daily and last only a few minutes. They are conducted in the site while the area is in operation and only a couple of production operators participate together with the maintenance technician and generally the maintenance supervisor and engineer. The main objective is to discuss equipment and installation maintenance issues. Therefore the focus is on reviewing the production log in order to improve the system performance.

Communication must be very precise between shifts. Detailed description of the problems faced during the shift of operation must be delivered to the corrective and preventive teams. Similarly, the shift responsible for the PM and system start up must inform any modifications performed in the equipment or anomalies found during setup procedures to the operations shift.

The last but probably most important aspect to analyze is the work environment. Safety and health are two conditions that must be guaranteed to every employee. Most organizations have a specific safety department that exclusively focuses on ensuring safe and healthy working conditions. Safety practices are an extensive field of study and will not be explained in detail in this work. For further information please refer to reference [12].

Another important component in a good work environment is resources availability. Both time and tools and spares are considered in Figure 6b. Assigning technicians to different areas is a critical task that must always consider the optimum operator / machine ratio. The analysis must relate the level of complexity of the area with technician skills and familiarity with the equipment. For example, for automatic lines that share electrical and mechanical equipment, at least two technicians must be assigned (one electrical and one mechanical). If it is a complex installation with several equipment, it might be needed to assign more maintenance people, especially if it is a critical system in the process.

2.5 Pillars dependency

One important characteristic is that most trees end with fundamental attributes that are common among pillar GTs. The REACTIVE pillar in Figure 2 shows that in order to ensure an effective action, tools and spares must be available. This can only be done through the LOGISTICS pillar. Similarly, personnel competence will be enhanced through proper TRAINING as well as personnel morale will depend on the success of the PEOPLE pillar. This means that the achievement of REACTIVE pillar is directly dependent on LOGISTICS, TRAINING and PEOPLE pillars. This dependency is repeatedly seen in most pillars as represented in Figure 7, showing a feedback process. Note that REACTIVE depends on all other pillars, while TRAINING is completely independent. The evident interdependency among five pillars determines the importance of achieving all the goals simultaneously. This conceptual result reinforces the assumption of assigning equal importance to each pillar.

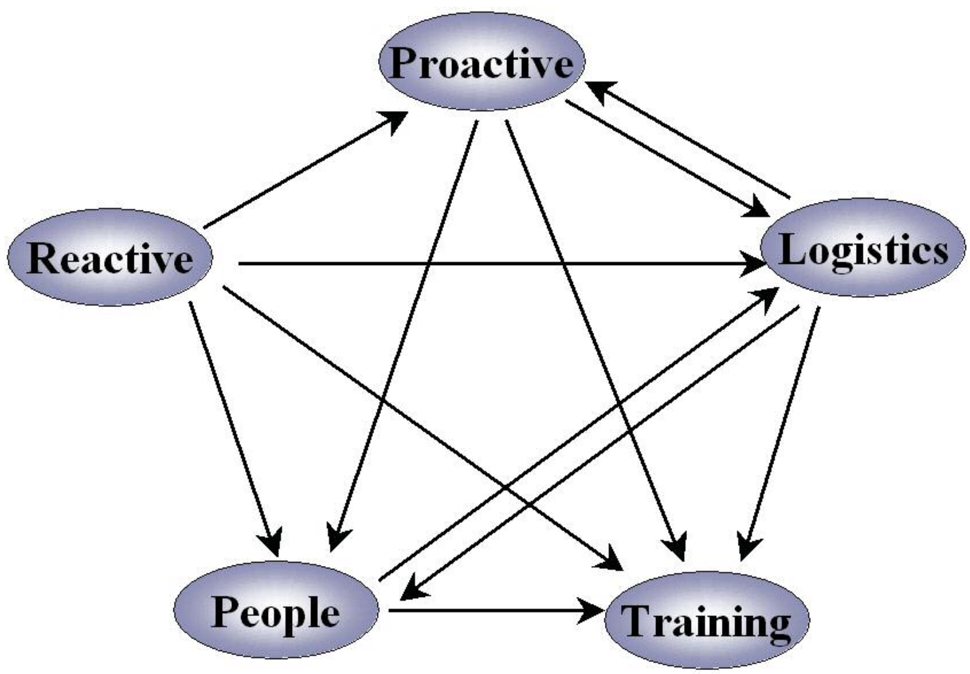

Figure 7. Pillars interdependency

2.6 Metrics Definition

Having developed the GTs, the focus shifts to the metric selection. In Figures 2 through 6 all fundamental attributes (shaded boxes) have a set of metrics assigned. There are few cases in which a specific performance indicator can fully monitor a particular attribute. On the contrary, it is more likely that several metrics would be needed to describe a behavior. For example for the "Develop easy to maintain equipment" attribute in the REACTIVE tree (Figure 2) three metrics are considered: Mean Time To Repair (MTTR), Number of Accidents or incidents, and Maintenance Satisfaction Index (MSI). It is expected that as the equipment becomes easier to maintain, both the time to repair and number of accidents or incidents decrease, while the satisfaction index increases. But there is one question that still remains: In what proportion does each metric represent the attribute fulfillment?

This question cannot be answered in a generic way. There are several context dependent situations that vary from application to application. Additionally, even though some aspects of maintenance practices are shared among different industries, there are some characteristics that differ considerably. For example, safety factors are probably the most critical in nuclear industry while reliability without regular inspections is essential for aerospace projects.

The GTs resulted in a total of 22 metrics that are seen simultaneously in the five pillars and in different levels of decomposition. Appendix A lists these metrics with their definition.

The GTs are developed considering all important aspects of maintenance practices. This general model is later customized to suit particular applications. The customization process will be carried out by assigning relative weights to each metric with respect to the attribute it monitors and also through weighting of the different alternative paths to achieving the pillars.

2.7 Weighting Metrics Using the Analytic Hierarchy Process

Assigning weight to the metrics is based on expert judgment. It is context dependent and thus depends on the industry for which the trees are being used. When analyzing the context one must understand the economical, social, political and cultural background as well as personnel competence, resource availability and equipment conditions. After considering all these variables, the Analytic Hierarchy Process (AHP) [5] can be used to determine the relative weight of the metrics.

The AHP is a decision making process to set priorities and to make the best decision when qualitative aspects of a decision must be considered. It is a systematic method for comparing a list of objectives or alternatives that reduces complex decisions to a series of one-to-one comparisons.

The first step of the process is to determine the relative strengths of the metrics in monitoring the attribute. The process consists of conducting a pairwise comparison of the metrics by posing the following question: Is M_1 metric preferred (or more important) over M_2 metric in measuring the attribute? At what level of intensity? The level of intensity can be subjectively assigned through a numeric scale ranging from 1 to 9, where 1 indicates equal importance and 9 absolute importance of M_1 over M_2. Table 2 shows the scale definition proposed by Saaty [5].

There is also a need to make a comparison among all associated attributes in meeting the higher-level goals. Figure 8 visualizes the comparison procedure. This block diagram shows a simplified example from the REACTIVE pillar. In order to perform a correct diagnosis of a failure, four conditions must be satisfied: increase

Table 2. AHP Scale definition

Intensity of importance	Definition	Explanation
1	Equally importance of both elements	Two elements contribute equally to the attribute
3	Weak importance of one element over another	Experience and judgment slightly favor on element over another
5	Essential or strong importance of one element over another	Experience and judgment strongly favor on element over another
7	Demonstrated importance of one element over another	An element is strongly favored and its dominance is demonstrated in practice
9	Absolute importance of one element over another	The evidence favoring one element over another is of the highest possible order of affirmation

personnel morale, improve personnel competence, develop a reliable monitoring system and implement troubleshooting procedures. Each of these attributes can be measured by one or more of the following metrics: Mean Time To Repair (MTTR), Maintenance Satisfaction Index (MSI), Overall Equipment Effectiveness (OEE), and Maintenance Costs.

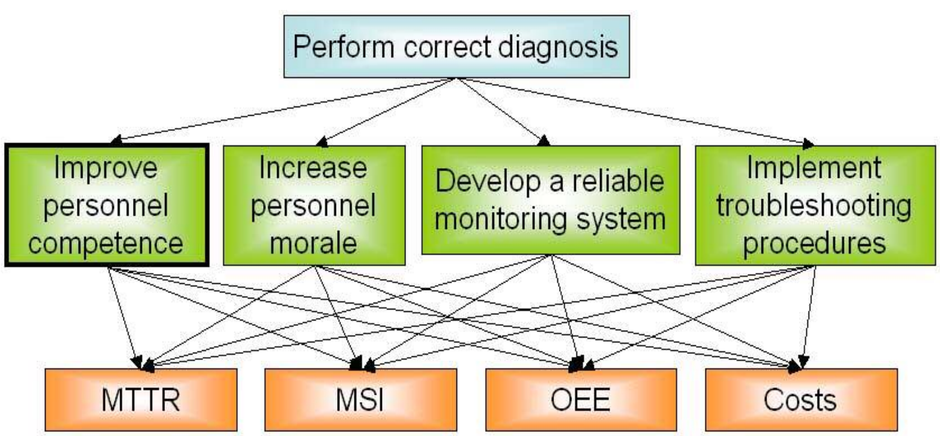

Figure 8. Application of the AHP in metric weighting

The methodology consists of evaluating the strength of the metrics in monitoring each of the four attributes with respect to "Perform correct diagnosis". One matrix per attribute is constructed as shown in Figure 9. Likewise, a criteria matrix is built to determine the attribute relative importance with respect to the goal.

	MTTR	MSI	OEE	Costs
MTTR	1	5	3	7
MSI	1/5	1	1/3	3
OEE	1/3	3	1	5
Costs	1/7	1/3	1/5	1

Increase personnel competence

	MTTR	MSI	OEE	Costs
MTTR	1	1/5	1	5
MSI	5	1	5	7
OEE	1	1/5	1	5
Costs	1/5	1/7	1/5	1

Increase personnel morale

	Morale	Personnel	Monitoring	TS
Morale	1	1/3	1/5	1/3
Personnel	3	1	1/3	3
Monitoring	5	3	1	3
TS	3	1/3	1/3	1

Criteria matrix

	MTTR	MSI	OEE	Costs
MTTR	1	5	3	7
MSI	1/5	1	1/3	3
OEE	1/3	3	1	5
Costs	1/7	1/3	1/5	1

Develop a reliable monitoring system

	MTTR	MSI	OEE	Costs
MTTR	1	5	3	7
MSI	1/5	1	1/3	3
OEE	1/3	3	1	5
Costs	1/7	1/3	1/5	1

Implement troubleshooting procedures

Figure 9. AHP matrices for "Perform correct diagnosis" simplified example

The complete solution will determine the metrics ranking with respect to the "Perform correct diagnosis" goal as summarized in Table 3. The attributes ranking appears in the first column while the metric ranking is indicated in each corresponding row. The overall ranking will be determined by combining each metric weight with the respective attribute weight. The AHP result for this example shows that MTTR is the most representative metric in measuring “Perform correct diagnosis” attribute, followed by OEE, then MSI and finally Maintenance Costs. Having these weights assigned, the problem is reduced by one level of decomposition and we move one step upward in the AHP analysis.

Table 3. AHP results for the simplified example on the correct diagnosis attribute

	MTTR	**MSI**	**OEE**	**Costs**
0.076 **Morale**	0.169	0.615	0.169	0.047
0.261 **Personnel**	0.564	0.118	0.263	0.055
0.513 **Monitoring**	0.564	0.118	0.263	0.055
0.150 **Troubleshooting**	0.564	0.118	0.263	0.055
Final Result	**0.534**	**0.156**	**0.256**	**0.054**

It is important to mention that there are generally too many metrics involved in the comparison. In order to transfer a limited set of metrics to the upper level, only those with high contribution are selected. The limit is imposed considering the Pareto rule of 80-20. For the analyzed example, the sum of MTTR, OEE and MSI contribution is 94.6 % and therefore “Costs” metric is not considered further.

The procedure is carried out starting from the lowest level attributes. The set of metrics and their ranking derived in this level will serve as the starting point for the next level comparison and this methodology will continue until reaching the pillar goal. Thus, the final indicators will closely reflect the pillar performance.

2.8 Considerations of Feedback

It was noted that feedback will be present in the GT model due to the dependency of the pillars. Such dependency leads to the existence of fundamental attributes that correspond to the main goal of a number of trees. For these attributes no metric can be effectively selected given that they will most likely differ in each tree.

In order to solve this recursive loop problem, a first set of estimated metrics will be considered for the attributes in question. Once the whole process has been conducted in the five pillars, the resulting indicators will now serve as an input for the second round of calculation. The iterative recalculation continues until no variation is observed in any of the five pillars resulting metrics.

Another approach to solve the pillars dependency is to use the Analytic Network Process (ANP) [13]. ANP is an enhanced approach to the AHP that supports dependencies and feedback. This theory adds networks to model dependencies among elements under the comparison process. This methodology was not applied in this study. It is left for future studies the application of the ANP and the analysis of how much the results differ from those obtained by the iteration process.

2.9 Analysis of scale selection and consistency

There are two aspects in the methodology that deserve detailed analysis: the scale selection and the level of consistency. Both concepts are closely related.

The scale proposed by Saaty ranges from 1 to 9 with clear qualitative definitions for the odd values as shown in Table 2. The intermediate values (2, 4, 6 and 8) are used when slight distinction is needed. There are several studies that provide different alternatives in the scale selection [14]. Some suggest quadratic and root square scales while others argue that the geometric scale is preferable. But integer scales yield to unevenly dispersed weights and therefore there is the alternative of a balanced scale where the local weights are evenly dispersed over the weight range [0.1, 0.9].

Clearly, the scale selection is highly subjective. For the purpose of this study, the linear 1-9 scale is chosen given that it is an easy way to represent the common verbal statements that the decision maker utilizes when making the metrics comparison. Nevertheless, this scale intransitive behavior must not be overlooked and the consistency results must be analyzed carefully.

Consistency is driven mainly by three factors. First, there must be a transitivity consistency. This means that if A is preferred over B and B is preferred over C, therefore A should be preferred over C. If this relation is not sustained, inconsistency will be generated. Nevertheless, there are real life cases where these types of inconsistencies are present. Such is the case of sport teams. It is not uncommon to see that A defeats B, B defeats C and C defeats A. This is a clear example that shows that inconsistency values must be analyzed carefully before assuming that there is judgment error.

The second factor affecting consistency is the numerical weights. If A is 3 times preferred over B and B is 3 times preferred over C, then, A should be 3 x 3 = 9 times preferred over C. Any value that does not arithmetically match this result will generate inconsistencies. This condition can represent an important source of uncertainty particularly for qualitative comparisons (the most commonly used in decision making). For this case, it is important to mention that the scale limit of 9 can also compromise the comparison process consistency. For example, if A is 3 times preferred over B and B is 5 times preferred over C, then A should be 3 x 5 = 15 times preferred over C. This value exceeds the upper limit of 9.

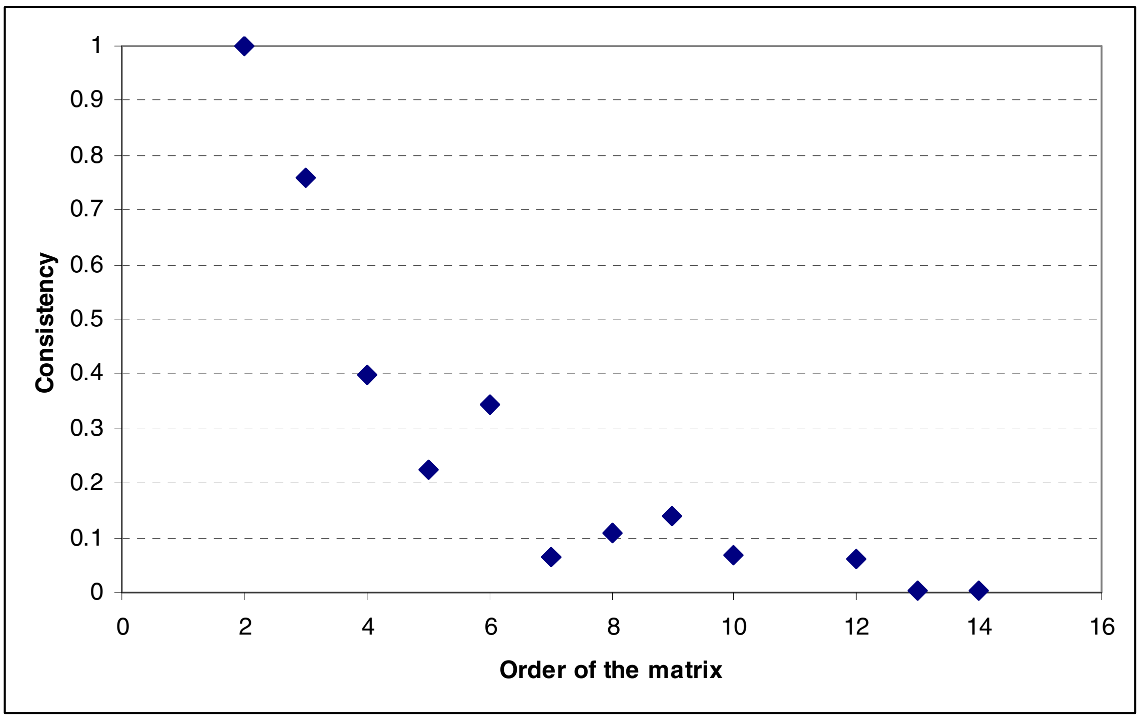

Figure 10. Consistency as a function of the order of the matrix

The third important factor is the size of the comparison matrix. The more elements being compared the greater the inconsistency. Figure 10 shows how the size of the matrix affects the consistency [5]. Note that as the number of elements to be compared increase the consistency value decrease. The problem becomes more complex for larger matrices. There is a psychological limit defined by the human capability of managing a certain amount of elements at the same time. The working memory capacity has been experimentally evaluated and it ranges from 5 to 9 items when full attention is deployed [15].

Having all these aspects into consideration, an acceptable level of consistency has to be defined. The consistency ratio (CR) is determined by a consistency index CI and a random index RI through the following expression:

$$CR = CI / RI$$

$$CI = (\lambda_{max} - n) / n - 1$$

The random index RI is tabulated and depends on the number of elements in the matrix:

n	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0.0	0.0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

T.L Saaty[5] suggests that a consistency ratio CR smaller than 0.1 or 10% is acceptable and for greater values a matrix revision should be made.

In this study, all matrices with CR greater than 10% have been carefully reviewed for transitivity and numerical inconsistencies. But given the important amount of high order matrices and significant metrics differences, there are several cases were the value of CR is greater than 10%. These values of inconsistency are acceptable especially in those cases were mainly a rank order is sought after.

Chapter 3: Case Study: Automotive Manufacturing

A particular case study was selected in order to put the proposed methodology into practice. The study determined the preferred metrics to monitor Maintenance Operations in Automotive Industries under a complex socio-economical environment.

3.1 Context Definition

This case study presents some particular characteristics that define the boundary conditions of the analysis. The following list summarizes these conditions:

- Stamping and Body Plant
- One shift of production
- Equipment in poor operating conditions
- Annual budget cut
- Annual head count reduction
- Minimum overtime
- Limited parts in stock
- Strong union representation
- Extreme currency devaluation making spare parts prices exceed the assigned maintenance budget
- There is a gap of knowledge between technicians and new technologies installed
- There is no economical aid from the Company Headquarters or from the Government due to global financial difficulties
- No budget is assigned for training. There is little or no external training

- High backlog due to poor equipment conditions and high amount of failures
- Morale: Due to difficult social and economic situation, people in all hierarchy levels are working under great pressure with low motivation

The consideration of these conditions will affect the pairwise comparison of the metrics, but will mostly alter the attributes importance. GTs in Figures 2 to 6 include the results from the attributes weight matrices. For example, in Figure 2 it can be seen that “Ensure tools and spares availability” together with “Improve personnel competence” are the most important attributes that must be satisfied to guarantee an effective repair. On the contrary, “Implement Quick Change Over and Error Proofing techniques” is the least significant.

Detailed results from the AHP can be found in Appendix B. Note that the previously mentioned iterative process leads to different results depending on the round of iteration. Additionally, the results are listed from higher to lower resulting weights and only those metrics with higher influence are selected. These most representative metrics are highlighted in the resulting tables.

The analysis result for this case study is summarized in Table 4. The metrics for PROACTIVE and LOGISTICS were selected using engineering judgment for the first iteration. From this selection the complete process was repeated deriving the set of leading indicators in the “2nd iteration”. The highlighted metrics are new in the pillar.

Table 4. Automotive industry case study results

<table>
<tr><th></th><th>1st iteration</th><th>2nd iteration</th><th>3rd iteration</th><th>BSC Metrics</th></tr>
<tr><td>REACTIVE</td><td>MTTR
MTBF
OEE
PM Plan
MSI
PM audits
CSI</td><td>OEE
MTTR
MSI
Costs
PM audits</td><td>OEE
MTTR
MSI
PM audits
Costs</td><td rowspan="5">MTTR
PM Audits
OEE
CSI
Costs
MSI
Overtime
Fill Rate
Inventory
Applicability
Accidents
WG status
MTBF
Items repaired</td></tr>
<tr><td>PROACTIVE</td><td>MTBF (*)
PM plan (*)
PM audits (*)
OEE (*)
CSI (*)</td><td>OEE
MSI
PM audits
Overtime
MTBF
Costs
CSI</td><td>OEE
MSI
PM audits
Overtime
MTBF
Costs
CSI</td></tr>
<tr><td>LOGISTICS</td><td>Fill rate (*)
Inventory (*)
MTTR (*)
OEE (*)
FTT repair (*)</td><td>Fill rate
Costs
MTTR
Inventory
Items repaired
OEE</td><td>Fill rate
Costs
OEE
Inventory
Items repaired
MTTR</td></tr>
<tr><td>TRAINING</td><td>Overtime
MSI
Applicability
Accidents
MTTR
Costs</td><td>Overtime
MSI
Applicability
Accidents
MTTR
Costs</td><td>Overtime
MSI
Applicability
Accidents
MTTR
Costs</td></tr>
<tr><td>PEOPLE</td><td>MSI
OEE
WG status
MTTR
Accidents
CSI</td><td>MSI
OEE
WG status
MTTR
Accidents
CSI</td><td>MSI
OEE
WG status
MTTR
Accidents
CSI</td></tr>
<tr><td colspan="5">(*) Metrics Estimated by Engineering Judgment</td></tr>
</table>

After three iterations, there were no further changes in the ranking and the final Balanced Scorecard metrics were obtained.

3.2 Sensitivity Analysis

Given the high number of fundamental attributes estimated and some complexity of comparison matrices, two different approaches have been selected to conduct a sensitivity analysis. One will focus on the importance of metrics weight and the other one on the importance of attributes weight.

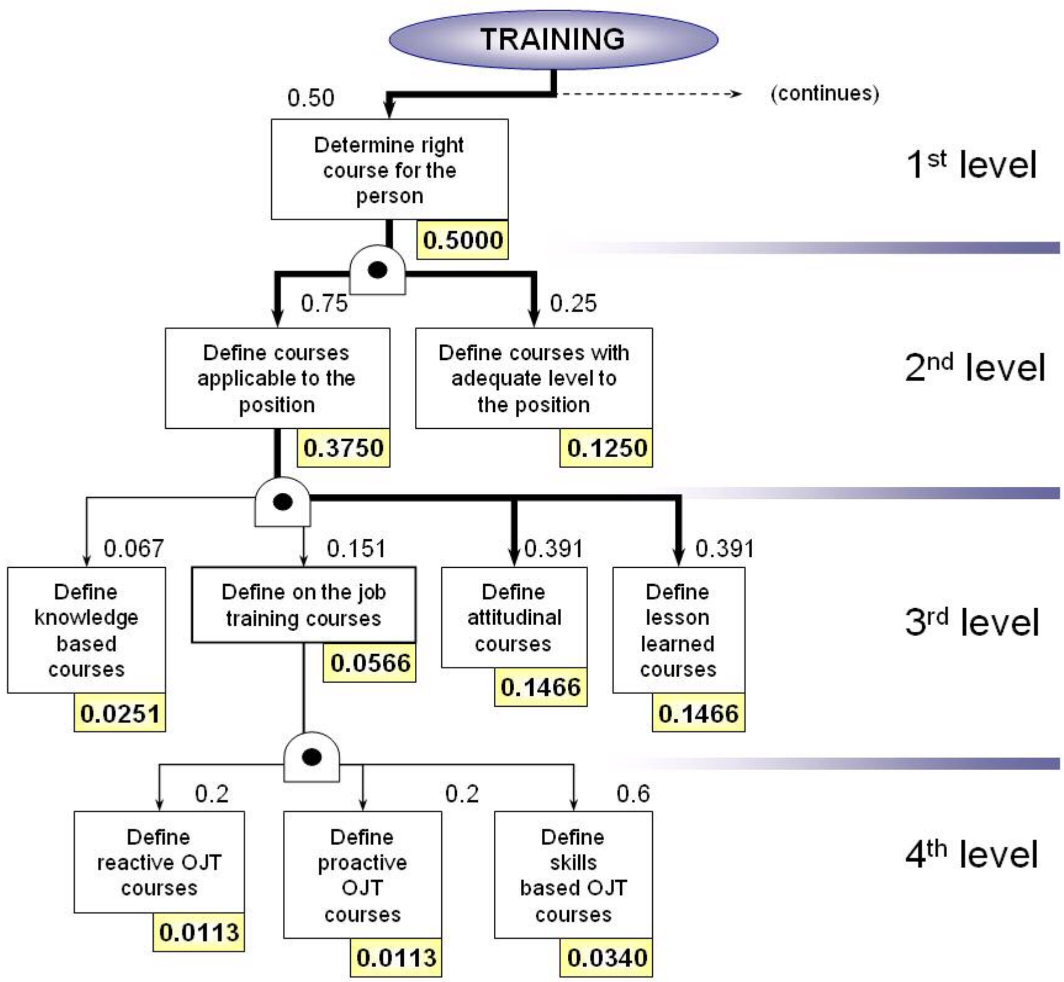

Figure 11. Attributes with high contribution to the TRAINING GT goal

For the metric sensitivity analysis, the attributes weights are kept constant throughout the tree decomposition. With these values, we will identify the most critical paths in each pillar. These can be calculated by multiplying each attribute weight at the different tree levels. The metrics to be evaluated will be those whose attributes weights are larger than 10% contribution to the main goal.

To help visualize this condition the path weights for "Determine right course for the person" from TRAINING Pillar are calculated. Figure 11 summarizes all resulting weights from this path. In addition to the individual attribute weights, each attribute's contribution to the TRAINING goal is shown. It is expected that attributes in higher levels have a higher contribution to the goal success. Thicker arrows in Figure 12 indicate those attributes that contribute in more than 10% to the main goal and whose metrics will be considered for the sensitivity analysis.

This methodology will lead to a limited set of attributes per pillar. Figure 12 lists the resulting attributes with their absolute influence over the goal and the level at which each attribute belongs. This representation shows that higher-level attributes have a greater influence on the pillar goal, which reinforces the conclusion that the metrics comparisons will be more critical as we move to the upper levels.

For each of these attributes, the metric sensitivity will be conducted. The procedure consists of varying the metric weight in one level of importance, for example from 3 to 5 in case of increasing relevance or from 9 to 7 for decreasing weight, given that the applied scale uses five absolute measures of importance (1,3,5,7 and 9). These sensible variations may result in metrics rank modification as well as new weight assignments. The resulting observations derived a group of high sensitive metrics and the corresponding AHP matrices were revised.

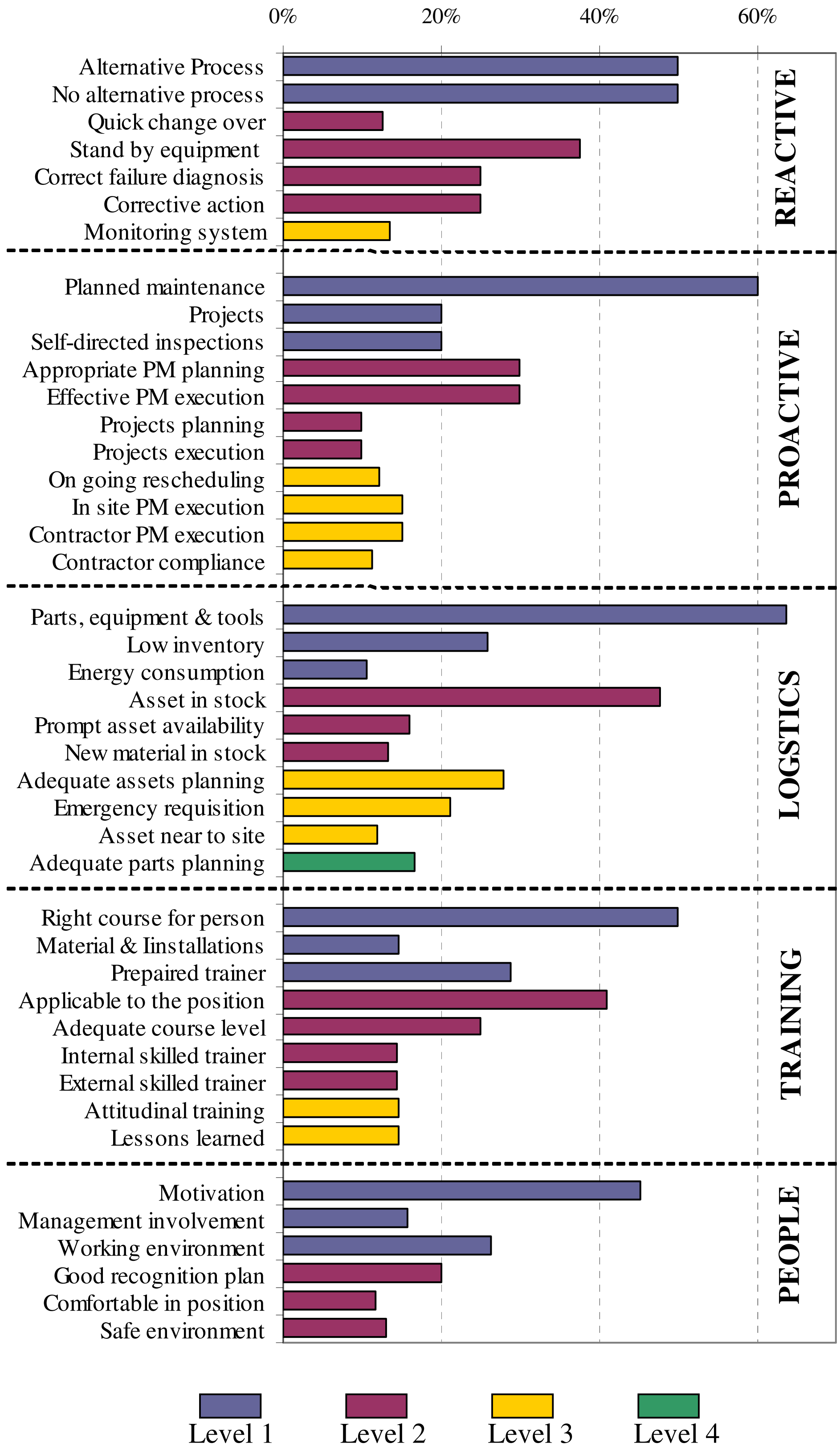

Figure 12. Attributes sensitive in the automotive industry case study

The second approach considers constant metric weights and varies the attribute relative values. The criteria immediately below the goal will be subjected to analysis given its dominance in the final result. The objective is to determine how minimum variations in criteria weighting will affect the resulting metrics. All attributes from the first level of decomposition are subjected to individual increased and decreased weights. Observations derived from this sensitivity analysis are listed per attribute within each of the five pillars in Table 5.

Table 5. Observations derived from the attribute sensitivity analysis conducted on the automotive industry case study

PILLAR	CRITERIA	INCREASING	DECREASING
REACTIVE	Manage repair actions through alternative process	- *OEE* remains the most relevant metric - *Maintenance costs* is no more representative of this pillar giving place to *Overtime* - *MTTR* decreases 45% moving from the second to the fourth place	- *OEE* remains the most relevant metric - *MTTR* remains the second indicator but increases its relevance in 45%
PROACTIVE	Maintain a good planned maintenance program	- *OEE* remains the most relevant metric - One metric less to measure the pillar since *CSI* is excluded - New *PM plan* metric is considered while *Costs* is no longer relevant	- *MSI* becomes the most important metric with a 14% increase followed by *Overtime* - *OEE* is reduced in 27% moving to the third place - *MTBF* is no longer considered giving place to *BTS* performance indicator - *PM audits* falls 40% moving to the last place
	Implement improvement projects	- *MSI* becomes the higher influence metric moving *OEE* to the second place - *CSI* is excluded giving place to *BTS*	- *OEE* remains the most relevant metric - *Costs* is excluded giving place to *BTS*
	Carry out self-directed maintenance	- *OEE* remains the most relevant metric - There is a significant increase in *CSI* relevance (65%) - *Costs* is excluded giving place to *BTS*	- There is no change in the first three metrics (*OEE, MSI* and *PM audits*) - *CSI* is no longer considered reducing the total amount of used metrics

PILLAR	CRITERIA	INCREASING	DECREASING
LOGISTICS	Ensure parts, equipment & tools availability	- There is no change in the first three metrics (*Fill rate, Cost* and *OEE*) - *Items repaired* is no longer considered reducing the total amount of used metrics from six to five	- *Costs* becomes the most important metric due to a 15% decrease in the *Fill Rate* metric relevance - *MTTR* is no longer considered giving place to *MSI*
	Minimize inventory	- There is no change in the first two metrics (*Fill Rate* and *Costs*) - *MTTR* is no longer considered reducing the total amount of used metrics from six to five	- There is no change in the first three metrics (*Fill Rate, Costs* and *OEE*) - *Inventory* drops 67% and is no longer considered giving place to *MSI*
	Optimize energy consumption	- There is no change in the first three metrics (*Fill Rate*, *Costs* and *OEE*) - Even though there is no significant variation in the metrics results, *Items repaired* gives place to *MSI*	- There is no change in the metrics ranking but the higher significance of the primary indicators results in one less metric needed (*MTTR*)
TRAINING	Determine right courses for the person	- Given the close final result weights, a slight variation of the attribute weight easily changes the metrics ranking - *Overtime* moves from first to fifth place - *Costs* is no longer considered giving place to *Understanding* metric	- There is no change in the first two metrics (*Overtime* and *MSI*) - *Accidents* drops 36% and is no longer considered giving place to *Backload* metric - *Costs* increases 27% moving from the sixth to the third place
	Have appropriate training material and installations	- *Overtime* remains the most important metric - *MSI* decreases 15% falling from second to fifth place	- *Overtime* and *MSI* switch first and second places
	Have prepared trainers	- No significant change in ranking or weights	- No significant change in ranking or weights
	Have people available for training	- There is no change in the first two metrics (*Overtime* and *MSI*) - It is observed a higher predominance of the first two metrics with respect to the rest of the set	- *Overtime* moves from first to third place after decreasing 13% - *Applicability* increases 13% moving from third to first place - *MSI* moves from second to fifth place after decreasing 12%

PILLAR	CRITERIA	INCREASING	DECREASING
PEOPLE	Increase employees motivation	- Even though there is no significant variation in the metrics results, *CSI* is no longer considered giving place to *Ideas implementation* - The main performance indicators gain more relevance	- *MSI* and *OEE* remain the first two metrics - *WG status* decreases 22% falling from the third to the sixth place - *Absenteeism* is added to the set of metrics
	Increase management involvement	- *MSI* remains the dominant metric - There is no significant variation in the final weights but some slight changes in ranking appear	- No significant variation is perceived
	Provide Employment planning	- No significant variation is perceived	- No significant variation is perceived
	Induce effective communication	- Even though there is no significant variation in the metrics results, *Accidents* is no longer considered giving place to *Ideas implementation*	- No significant variation is perceived
	Provide with a good work environment	- There is no change in the first two metrics (*MSI* and *OEE*) - *WG status* decreases in 20% falling from third to sixth place	- Even though there is no significant variation in the metrics results, *CSI* is no longer considered giving place *to Ideas implementation*

Similar to the metric sensitivity analysis discussed earlier, the result from the attribute sensitivity analysis indicated particular matrices to be carefully reviewed.

3.3 Results

The application of the methodology to the automotive industry resulted in a small set of metrics to monitor and effectively manage maintenance operations. These metrics listed in Table 4 resulted from the systematic decompositions of some pillars of effective maintenance along with AHP ranking.

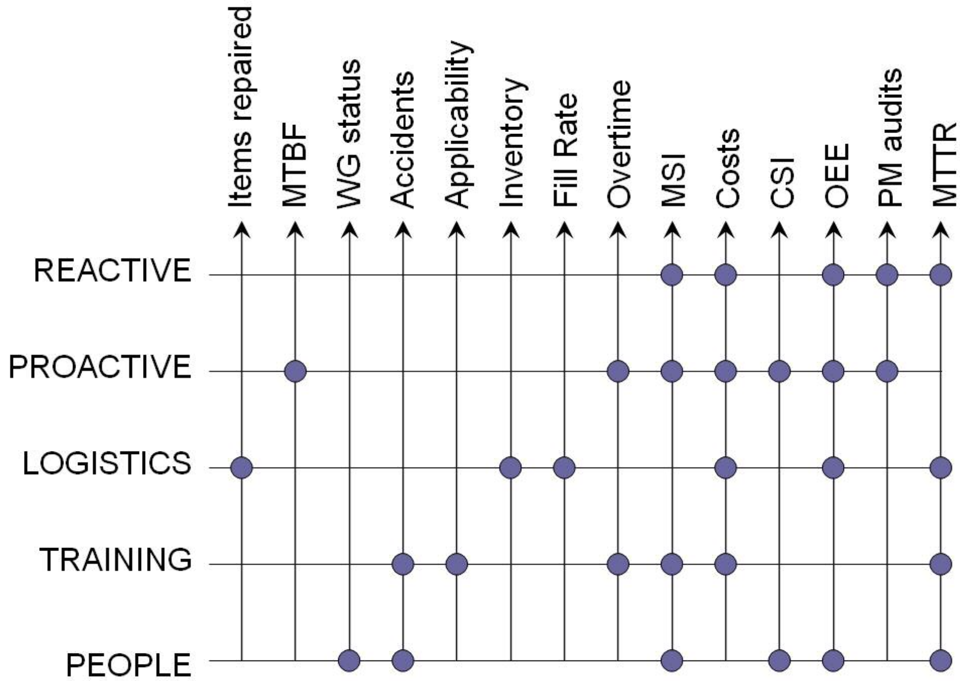

Figure 13. Metrics and Pillars dependency for the automotive case study

Figure 13 helps visualize the dependencies of the resulting metrics with the pillars. For example, CSI will monitor both PROACTIVE and PEOPLE pillars. Similarly, indicators such as Items Repaired, Inventory and Fill Rate will only monitor LOGISTICS pillar. We can also use Figure 13 to depict which metric will reveal a particular pillar performance. Additionally, Figure 14 details the relative importance of each metric to the pillar goal. Note that in Figure 14 a there is a strong dominance of OEE over the other performance indicators. This means that for this particular case study, the REACTIVE pillar can be primarily monitored by the OEE metric. From a management point of view, focusing on improving OEE will result in an important improvement of the REACTIVE pillar.

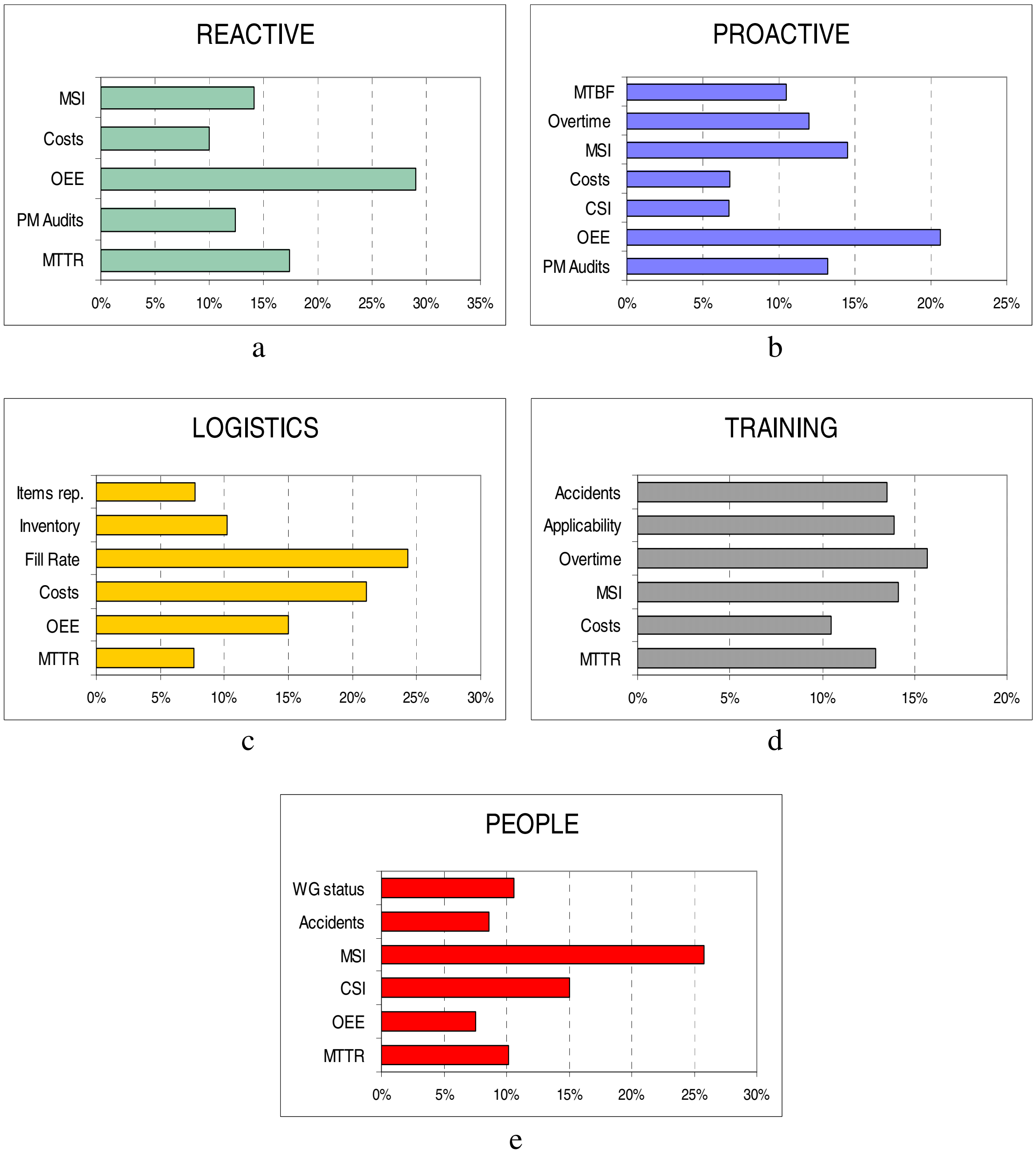

Figure 14. Relative influence of the resulting metrics over each pillar

This same analysis can easily be derived from Figure 15. In this figure we can see the how each metric can monitor different pillars. As an example let us focus on

Accidents. This metric is shown to monitor both PEOPLE and TRAINING pillars. In order to reduce the number of accidents, the resources should be invested in these two pillars with a slight preference on TRAINING.

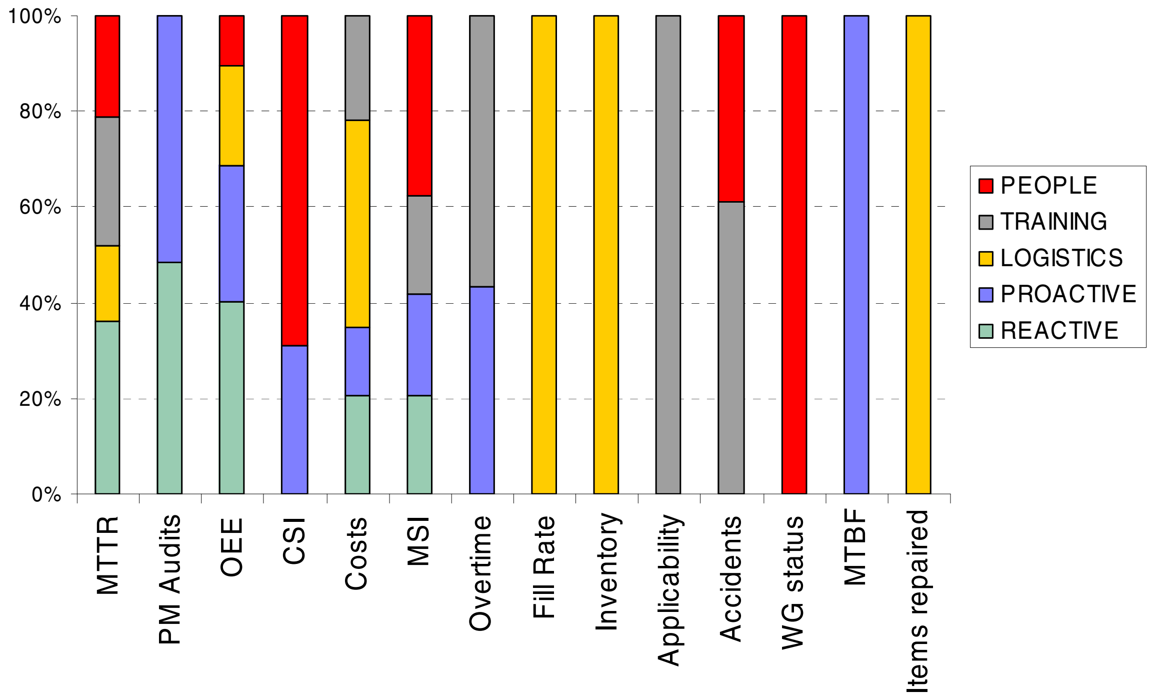

Figure15. Pillars monitored per metric

Similarly, transposing this chart we can obtain the resulting performance indicators that will monitor each pillar as shown in Figure 16. This representation is particularly useful for management decision making since it clearly shows the relative importance each metric has in monitoring a particular pillar.

Again, the dominance of OEE as the strongest metric for measuring the REACTIVE pillar can easily be seen. Similarly, this figure also shows that MSI metric is the most relevant metric for measuring PEOPLE pillar.

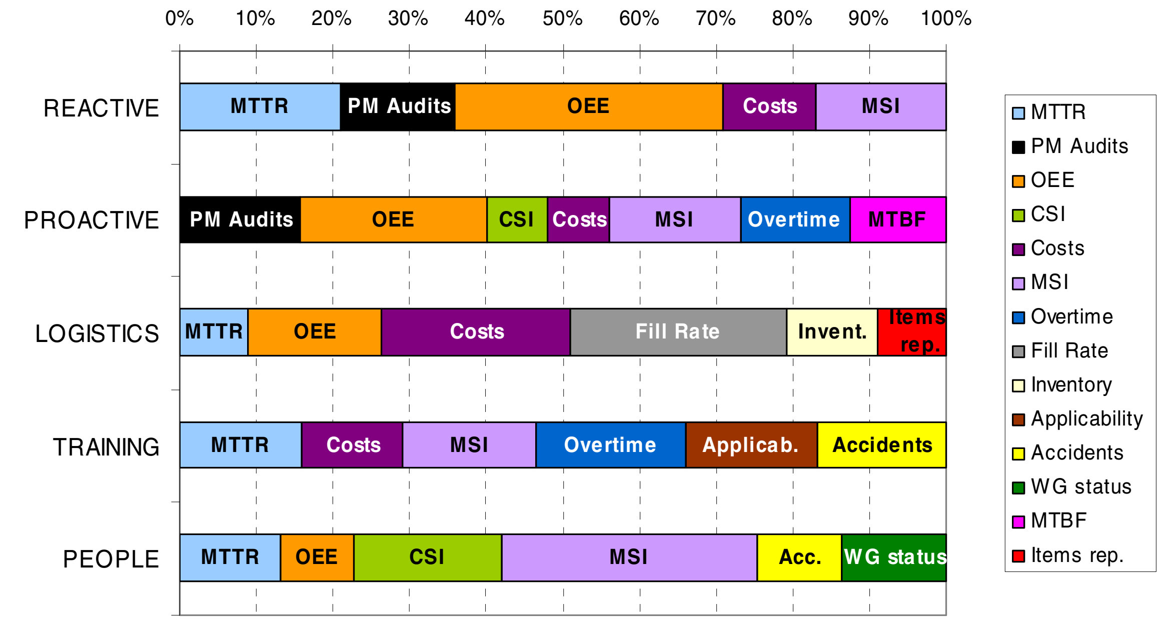

Figure 16. Resulting metrics with their relative weights per Pillar

The proposed method shows what should be monitored to maximize performance of maintenance operations. It also provides the fundamentals to a structured and result-oriented management planning.

The sensitivity analysis reinforces the importance of the higher-level attributes in the final results indicating that the metric weighting should be conducted more carefully as we approach the top level. Additionally, those metrics that are sensitive for each critical path are identified so that judgments regarding ranking of the metrics can be modified, if necessary.

Chapter 4: Conclusions

After developing the GTs for each of the five fundamental pillars a group of attributes was derived. Many of these attributes are replicated in more than one pillar showing that there is a close interdependency among the pillars. Moreover, the presence of closed feedback loops indicates the importance of focusing on all pillars simultaneously in order to ensure optimal maintenance performance.

It is observed that most attributes share the same indicators. This means that a variation in a single attribute can modify more than one performance indicators. Also, each metric depends on the success of a number of attributes from different pillars. Therefore, the metrics and attributes show a many-to-many relationship. Decision makers are encountered with this complex model often. The GT decomposition followed by the application of the AHP helped clarify the model dependencies.

An important advantage of this methodology is that GT decomposition provided with a general model for maintenance operations. The model can be further customized by applying the AHP to fit particular applications.

This study provides a complete and integrated methodology for maintenance related activities. The systematic development of the goal trees allows identification of all the main attributes that should be in place for reliable and safe operations. At the same time, the qualitative hierarchical arrangement of the metrics provides a means of selecting those that will better monitor maintenance performance.

A case study was performed and results are consistent with expectation. Most of the resulting metrics are suggested by maintenance management literature. This practical application derived these metrics in a methodic way and at the same time provided with relative weights for each of the five pillars of the strategy.

Chapter 5: Future Work

5.1 On the GT decomposition

The hierarchical decomposition has been conducted by the author and has been reviewed by another maintenance management expert. Given the complexity of different maintenance practices and the diverse industries and applications, future improvement can be made in the GT development. A team of maintenance experts from different industries can be built in order to conduct a thorough revision of the decomposition and ensure it is applicable to all kind of industries.

Additionally, a similar group analysis can be conducted by a cross functional team integrated by experts from the fields of Human Resources, Personnel Development and Training and Logistics and Material Handling.

5.2 On the metrics quantification

Given that the AHP quantification is performed by expert judgment it tends to be subjective and dependent on the analyst personal experience. In this work the metric and attribute comparison was conducted only by the author to show the methodology. In order to obtain a more objective result an expert elicitation process should be conducted. Similar to the GT decomposition, this team should involve experts in the maintenance field as well as other cross functional areas.

5.3 On the consideration of feedback

In the present work the presence of feedback among pillars was solved using an iterative process. Three iterations have been conducted to obtain the resulting performance indicators. The use of ANP[13] has only been mentioned as an alternative to this problem. Future work should focus on implementing the ANP to address feedback and compare these results with those presented in this study.

Appendices

Appendix A: Metric Definitions

Accidents: Defines the number of accidents and incidents per period of time. It is usually monthly kept and includes the year accumulate. This metric focuses on human injury. Some organizations also include property damage as part of this report.

An incident is an event that has the potential to cause damage to personnel. Accidents are usually divided by severity into mayor accidents and minor accidents. Therefore, three values are represented:

Applicability: As a training metric, it measures how applicable the course is to the student's job position. It is usually a qualitative indicator. In order to measure the complete training program the average applicability for all the courses on the period is calculated. Numeric applicability values can be assigned to the qualitative statement to facilitate the graphic representation. Then, the sum of these applicability values over the number of courses in the time period is plotted.

Backlog: The backlog can be measured with the work order system by keeping appropriate record of the work order status. This metric measures the amount of work orders (WO) opened and pending for the time period and the ratio of closed WO vs. total WO. In order to see if the backlog is increasing or decreasing, the cumulative values are also represented.

BTS: BTS stands for Build To Schedule. It is an operational metric that represent how well the plant produced the correct volume, mix, and sequence according to customer requirements.

Cases: "Case" is the name given to a complete failure analysis that includes the study of why the failure happened (MTBF analysis) and why it took that amount of time to implement the corrective action (MTTR analysis). Additionally, one "case" includes the containment and definitive corrective actions with the corresponding implementation plan. A case is to be close when the root cause was determined and the definitive corrective actions were implemented.

This metric shows the number of opened cases versus the total number of failures occurred as well as the ratio of opened versus closed cases.

Costs: There are several ways to measure maintenance costs. Two of the most common are Maintenance cost per unit manufactured and Maintenance cost per total manufacturing costs. It is common to see maintenance costs split in materials costs and manpower costs. The latest also includes over time.

CSI: CSI stands for Customer Satisfaction Index. This metric will represent how satisfied Production department is with maintenance performance. In order to gather this information, surveys are commonly used.

Fill rate: Fill rate is a material flow performance indicator that represents the ratio of parts provided versus parts requested.

FTT repair: FTT stands for First Time Through. This metric is usually used in manufacturing to measure the percentage of good units manufactured in the first round. It is calculated by dividing the number of units minus any defects by the total number of units.

This concept can be used for repaired items to measure the quality of the repair. In this case, the metrics will represent the ratio of working repaired units divided by the total units that have been repaired.

Ideas Implementation: This metric will measure how many improvement ideas have been proposed by the organization personnel and also the percentage of those that were effectively implemented.

Items repaired: This is a simple indication of total items repaired over the total items failed.

Inventory: There are to variables that must be considered when measuring inventory. The first one is the total number of items in stock and the second one is the total cost of these items. Generally both values are indicated. The stock inactivity can also be included in this metric computing the inactive stock items divided the total stock items.

MSI: Maintenance Satisfaction Index (MSI) represents the moral of maintenance employees. Similar to the Customer Satisfaction Index, this indicator is derived from appropriate surveys.

MTBF: Mean Time Between Failure measures the breakdown frequency. It is computed as the considered time period divided by the number of breakdowns.

MTTR: Mean Time To Repair as its name clearly indicates, shows the average time to repair. It is computed as the total downtime divided by the number of breakdowns.

OEE: The Overall Equipment Effectiveness combines three different measures as follows:

$$\text{OEE} = \text{Availability} \times \text{Performance} \times \text{Quality}$$

Where

$$\text{Availability} = \text{Operating Time} / \text{Planned Production Time}$$

$$\text{Performance} = \text{Ideal Cycle Time} / (\text{Operating Time} / \text{Total Pieces})$$

$$\text{Quality} = \text{Good Pieces} / \text{Total Pieces}$$

Overtime: Overtime is the amount of time someone works beyond normal working hours. This metric can be represented by total overtime per period of time or by total overtime cost per period of time.

PM audits: In order to improve the preventive maintenance practices, TPM establishes an audit system that consists of randomly select 5% of the total PM work orders and check its compliance and also asses the quality of the work performed. The amount of WO audited with open issues vs. total audited WO is plotted. This performance indicator can help identify training needs as well as the need to rebalance the amount of PM activities.

PM plan: This metric represents the compliance of the PM plan through the plotting of total PM work orders closed versus total planed PM work orders.

System audits: System audit can be performed on computerized maintenance management system, (CMMS) or the material planning system. This performance indicator is similar to PM audits in that 5% of the items are audited and those with observations are divided by the total of the items audited and the result is then plotted.

Troubleshooting: Troubleshooting provides a systematic means of searching for the source of a problem so that it can be solved. All critical equipment must have a comprehensive documentation that is used to guide the analyst thourgh the troubleshooting process.

This metric shows how many equipment have troubleshooting documentation over the total plant equipment.

Understanding: This training performance indicator measures how effectively the concepts explained in a certain course have been transmitted. In order to measure this level of learning it is necessary that all courses include a brief examination to test the participant's learning process.

The average score of the examination is computed per course and the average of the all the courses results per period of time is represented.

WG status or Work Group Status: This indicator only applies to those organizations that have work cells in place. There are many ways to measure how mature the work group is and it is highly related to the type of organization. One example of this technique is using the 10 pillars of Lean Manufacturing and measuring the results in each pillar. The more mature the group is the more advanced Lean manufacturing indicators will be.

Appendix B: Analytic Hierarchy Process results

REACTIVE Pillar

ENSURE PROPER DATA COLLECTION AND ANALYSIS

1st, 2nd and 3rd iteration:

	0.067 WG meetings	0.391 In site meetings	0.151 Database	0.391 Cases	Final Result
OEE	0.088	0.289	0.110	0.145	0.192
Cases	0.027	0.029	0.034	0.371	0.163
MTTR	0.088	0.160	0.110	0.145	0.142
BTS	0.034	0.210	0.015	0.081	0.118
MTBF	0.088	0.058	0.110	0.145	0.102
MSI	0.178	0.100	0.033	0.019	0.064
5% Audits	0.009	0.008	0.373	0.008	0.063
CSI	0.178	0.100	0.011	0.019	0.060
Backload	0.022	0.022	0.182	0.037	0.052
WG	0.288	0.023	0.021	0.029	0.043

INDUCE EFFECTIVE COMMUNICATION

1st, 2nd and 3rd iteration:

	0.250 Meetings	0.750 Training	Final Result
Overtime	0.014	0.302	0.230
MSI	0.160	0.224	0.208
Applicability	0.013	0.165	0.127
Accidents	0.111	0.111	0.111
WG	0.309	0.023	0.095
MTTR	0.073	0.083	0.080
Ideas implementation	0.222	0.012	0.064
Costs	0.027	0.049	0.044
MTBF	0.073	0.031	0.041

KEEP AN UPDATED LESSON LEARNED SYSTEM

1st, 2nd and 3rd iteration:

	0.250	0.750	Final
	Data analysis	Communication	Result
Overtime	0.010	0.281	0.214
MSI	0.065	0.215	0.177
Applicability	0.010	0.158	0.121
Accidents	0.023	0.115	0.092
OEE	0.280	0.025	0.089
MTTR	0.163	0.056	0.083
WG status	0.036	0.085	0.072
Cases	0.214	0.010	0.061
MTBF	0.085	0.036	0.048
BTS	0.115	0.019	0.043

PERFORM CORRECT DIAGNOSIS

1st, 2nd and 3rd iteration:

	0.043	0.232	0.541	0.092	0.092	Final
	Morale	Personnel	Monitoring Sys.	Lesson Learned	Troubleshooting	Result
MTTR	0.114	0.106	0.323	0.055	0.233	0.230
OEE	0.218	0.157	0.240	0.074	0.182	0.199
MSI	0.285	0.212	0.171	0.214	0.108	0.184
Costs	0.021	0.305	0.071	0.014	0.059	0.117
Troubleshooting	0.012	0.009	0.102	0.018	0.292	0.086
Overtime	0.039	0.074	0.019	0.291	0.012	0.057
Applicability	0.012	0.050	0.018	0.154	0.043	0.040
Accidents	0.084	0.035	0.020	0.112	0.035	0.036
WG	0.157	0.022	0.018	0.038	0.018	0.027
CSI	0.059	0.030	0.018	0.028	0.019	0.024

IMPROVE IN SITE PERSONNEL COMPETENCE

1st, 2nd and 3rd iteration:

	0.500	0.500	Final
	Training	Right position	Result
MSI	0.221	0.224	0.223
OEE	0.030	0.314	0.172
Overtime	0.316	0.024	0.170
MTTR	0.076	0.160	0.118
Applicability	0.164	0.017	0.091
Accidents	0.110	0.032	0.071
CSI	0.016	0.110	0.063
MTBF	0.028	0.077	0.052
Costs	0.039	0.043	0.041

IMPROVE PERSONNEL COMPETENCE

1st, 2nd and 3rd iteration:

	0.500	0.500	Final
	In site	Contractor	Result
Costs	0.019	0.428	0.224
OEE	0.246	0.184	0.215
MSI	0.362	0.053	0.207
MTTR	0.102	0.184	0.143
Overtime	0.161	0.115	0.138
Applicability	0.069	0.017	0.043
Accidents	0.042	0.019	0.030

GUARANTEE AN EFFECTIVE ACTION

1st iteration:

	0.494	0.036	0.243	0.113	0.113	Final
	Tools / spares	EP / QCO	Personnel	Morale	Maintainability	Result
MTTR	0.175	0.300	0.126	0.115	0.311	0.176
OEE	0.126	0.214	0.165	0.214	0.220	0.159
Fill rate	0.303	0.109	0.012	0.011	0.010	0.159
MSI	0.065	0.060	0.217	0.281	0.158	0.137
Inventory	0.218	0.024	0.012	0.011	0.021	0.115
Cost	0.038	0.060	0.275	0.016	0.030	0.093
Accidents	0.030	0.103	0.051	0.087	0.069	0.049
Overtime	0.011	0.009	0.090	0.042	0.120	0.046
CSI	0.021	0.087	0.039	0.063	0.053	0.036
WG status	0.014	0.034	0.012	0.158	0.010	0.030

2nd iteration:

	0.344	0.054	0.344	0.129	0.129	Final
	Tools / spares	EP / QCO	Personnel	Morale	Maintainability	Result
Cost	0.213	0.060	0.280	0.019	0.061	0.183
MTTR	0.153	0.300	0.135	0.119	0.318	0.172
MSI	0.042	0.060	0.221	0.281	0.179	0.153
OEE	0.056	0.214	0.177	0.215	0.243	0.151
Fill rate	0.289	0.109	0.015	0.014	0.017	0.114
Accidents	0.016	0.103	0.071	0.090	0.095	0.060
Inventory	0.111	0.024	0.015	0.014	0.017	0.049
WG status	0.031	0.034	0.015	0.164	0.017	0.041
CSI	0.009	0.087	0.055	0.069	0.034	0.040
Items repaired	0.080	0.009	0.015	0.015	0.017	0.038

3rd iteration:

	0.344 Tools / spares	0.054 EP / QCO	0.344 Personnel	0.129 Morale	0.129 Maintainability	Final Result
Cost	0.212	0.056	0.280	0.022	0.061	0.183
MTTR	0.111	0.305	0.135	0.119	0.318	0.158
OEE	0.064	0.217	0.177	0.214	0.243	0.154
MSI	0.041	0.061	0.221	0.281	0.179	0.153
Fill rate	0.288	0.107	0.015	0.014	0.017	0.114
Inventory	0.149	0.020	0.015	0.014	0.017	0.061
Accidents	0.015	0.096	0.071	0.090	0.095	0.059
WG status	0.029	0.032	0.015	0.164	0.017	0.040
CSI	0.009	0.086	0.055	0.069	0.034	0.040
Items repaired	0.080	0.020	0.015	0.014	0.017	0.038

MANAGE REPAIR ACTIONS WITHOUT ALTERNATIVE PROCESS

1st iteration:

	0.500 Diagnosis	0.500 Action	Final Result
MTTR	0.326	0.330	0.328
OEE	0.232	0.235	0.234
MSI	0.166	0.103	0.134
Fill Rate	0.015	0.161	0.088
Costs	0.111	0.049	0.080
TS	0.079	0.019	0.049
Inventory	0.015	0.074	0.044
Overtime	0.056	0.028	0.042

2nd iteration:

	0.500 Diagnosis	0.500 Action	Final Result
MTTR	0.363	0.239	0.301
Cost	0.109	0.369	0.239
OEE	0.247	0.106	0.177
MSI	0.160	0.162	0.161
Troubleshooting	0.074	0.016	0.045
Fill Rate	0.017	0.067	0.042
Accidents	0.031	0.040	0.036

3rd iteration:

	0.500 Diagnosis	0.500 Action	Final Result
MTTR	0.364	0.164	0.264
OEE	0.247	0.242	0.245
Cost	0.114	0.357	0.235
MSI	0.168	0.104	0.136
Fill Rate	0.020	0.071	0.045
Troubleshooting	0.066	0.015	0.040
Inventory	0.020	0.048	0.034

IMPLEMENT QUICK CHANGE OVER

1st, 2nd and 3rd iteration:

	0.250 Procedures	0.750 Communication	Final Result
WG status	0.116	0.394	0.324
CSI	0.040	0.203	0.162
MSI	0.022	0.203	0.157
BTS	0.424	0.065	0.155
OEE	0.258	0.085	0.128
Accidents	0.081	0.022	0.037
MTTR	0.059	0.029	0.036

MANAGE REPAIR ACTIONS THROUGH ALTERNATIVE PROCESS

1st iteration:

	0.250 QCO	0.750 Equipment	Final Result
MTBF	0.019	0.347	0.265
PM plan	0.019	0.214	0.165
5% audits	0.019	0.214	0.165
CSI	0.237	0.063	0.106
WG	0.332	0.019	0.098
OEE	0.086	0.086	0.086
MSI	0.169	0.039	0.072
BTS	0.120	0.018	0.044

2^{nd} and 3^{rd} iteration:

	0.250 QCO	0.750 Equipment	Final Result
OEE	0.091	0.290	0.240
PM audits	0.015	0.214	0.164
MSI	0.164	0.158	0.159
Overtime	0.015	0.108	0.085
WG	0.281	0.012	0.080
CSI	0.215	0.028	0.075
PM plan	0.015	0.078	0.062
Costs	0.069	0.055	0.058
BTS	0.119	0.020	0.045
MTBF	0.015	0.038	0.033

REACTIVE PILLAR RESULT

1^{st} iteration:

	0.500 Alt. Proc.	0.500 No Alt. Proc.	Final Result
MTTR	0.025	0.291	0.158
MTBF	0.288	0.019	0.153
OEE	0.059	0.222	0.141
PM plan	0.212	0.012	0.112
MSI	0.038	0.161	0.100
5% audits	0.162	0.012	0.087
CSI	0.107	0.051	0.079
Fill Rate	0.017	0.119	0.068
WG status	0.078	0.026	0.052
Costs	0.015	0.086	0.051

2^{nd} iteration:

	0.500 Alt. Proc.	0.500 No Alt. Proc.	Final Result
OEE	0.330	0.184	0.257
MTTR	0.027	0.332	0.179
MSI	0.161	0.123	0.142
Costs	0.019	0.237	0.128
5% audits	0.235	0.014	0.125
Overtime	0.103	0.036	0.069
CSI	0.052	0.052	0.052
WG status	0.073	0.023	0.048

3rd iteration:

	0.500	0.500	Final
	Alt. Proc.	No Alt. Proc.	Result
OEE	0.330	0.250	0.290
MTTR	0.019	0.330	0.174
MSI	0.161	0.122	0.141
PM audits	0.235	0.013	0.124
Costs	0.028	0.171	0.100
Overtime	0.101	0.053	0.077
WG status	0.074	0.022	0.048
CSI	0.052	0.039	0.046

PROACTIVE Pillar

ENSURE PROPER DATA COLLECTION AND ANALYSIS

1st, 2nd and 3rd iteration:

	0.067	0.391	0.151	0.391	Final
	WG meetings	In site meetings	Database	Cases	Result
OEE	0.088	0.289	0.110	0.145	0.192
Cases	0.027	0.029	0.034	0.371	0.163
MTTR	0.088	0.160	0.110	0.145	0.142
BTS	0.034	0.210	0.015	0.081	0.118
MTBF	0.088	0.058	0.110	0.145	0.102
MSI	0.178	0.100	0.033	0.019	0.064
5% Audits	0.009	0.008	0.373	0.008	0.063
CSI	0.178	0.100	0.011	0.019	0.060
Backload	0.022	0.022	0.182	0.037	0.052
WG	0.288	0.023	0.021	0.029	0.043

CONDUCT THOROUGH RELIABILITY ANALYSIS

1st, 2nd and 3rd iteration:

	0.258	0.637	0.105	Final
	Training	Data analysis	Resources	Result
OEE	0.037	0.217	0.216	0.171
MTBF	0.060	0.206	0.036	0.151
Cases	0.011	0.206	0.010	0.135
MSI	0.217	0.064	0.283	0.127
MTTR	0.081	0.133	0.121	0.118
Overtime	0.285	0.012	0.052	0.086
BTS	0.024	0.096	0.026	0.070
Accidents	0.116	0.016	0.087	0.050
Applicability	0.152	0.012	0.010	0.048
WG status	0.015	0.036	0.159	0.044

KEEP A RELIABLE WO AND CMMS SYSTEM

1^{st}, 2^{nd} and 3^{rd} iteration:

	0.150	0.513	0.076	0.261	Final
	Personnel	User friendly	Integration	Resource	Result
MSI	0.284	0.219	0.020	0.197	0.208
WO system Audits	0.015	0.326	0.310	0.032	0.201
Overtime	0.039	0.084	0.145	0.315	0.142
CSI	0.058	0.173	0.020	0.103	0.126
OEE	0.217	0.023	0.053	0.102	0.075
Backload	0.021	0.051	0.086	0.114	0.066
WG status	0.160	0.053	0.092	0.015	0.062
Costs	0.021	0.035	0.212	0.047	0.050
MTTR	0.105	0.023	0.050	0.059	0.047
Accidents	0.080	0.013	0.011	0.016	0.024

CONDUCT APPROPRIATE PLANNING

1^{st}, 2^{nd} and 3^{rd} iteration:

	0.066	0.257	0.042	0.104	0.404	0.127	Final
	WO	Reliability	Cases	Bottle neck	Rescheduling	Equipment avail.	Result
OEE	0.088	0.287	0.204	0.194	0.166	0.185	0.199
MBF	0.027	0.219	0.204	0.119	0.206	0.114	0.177
PM plan	0.042	0.101	0.091	0.113	0.289	0.049	0.167
Overtime	0.156	0.027	0.009	0.264	0.020	0.300	0.091
Cases	0.011	0.162	0.284	0.056	0.058	0.011	0.085
BTS	0.012	0.022	0.077	0.123	0.076	0.185	0.077
CSI	0.115	0.011	0.025	0.059	0.095	0.058	0.063
MSI	0.287	0.062	0.037	0.025	0.036	0.068	0.062
Costs	0.042	0.074	0.053	0.036	0.045	0.020	0.048
WO sys. Audits	0.219	0.036	0.015	0.010	0.009	0.011	0.030

IMPROVE IN SITE PERSONNEL COMPETENCE

1^{st}, 2^{nd} and 3^{rd} iteration:

	0.500	0.500	Final
	Training	Right position	Result
MSI	0.221	0.224	0.223
OEE	0.030	0.314	0.172
Overtime	0.316	0.024	0.170
MTTR	0.076	0.160	0.118
Applicability	0.164	0.017	0.091
Accidents	0.110	0.032	0.071
CSI	0.016	0.110	0.063
MTBF	0.028	0.077	0.052
Costs	0.039	0.043	0.041

GUARANTEE IN SITE EFFECTIVE ACTION

1^{st}, 2^{nd} and 3^{rd} iteration:

	0.133	0.362	0.133	0.251	0.045	0.077	Final
	Tools & spares	Personnel	Morale	Compliance	Repairs prog.	Clear tasks	Result
MSI	0.072	0.312	0.289	0.040	0.316	0.244	0.204
OEE	0.097	0.238	0.221	0.106	0.155	0.120	0.171
PM audits	0.010	0.053	0.029	0.262	0.017	0.297	0.114
MTTR	0.170	0.171	0.118	0.011	0.017	0.013	0.105
MTBF	0.030	0.083	0.060	0.163	0.054	0.150	0.097
PM plan	0.040	0.028	0.012	0.262	0.017	0.025	0.086
Costs	0.226	0.015	0.053	0.056	0.053	0.052	0.063
WG status	0.053	0.038	0.177	0.018	0.111	0.072	0.059
WO audits	0.010	0.053	0.030	0.070	0.245	0.013	0.054
Fill rate	0.292	0.009	0.011	0.011	0.015	0.013	0.048

ENSURE CONTRACTOR EFFECTIVE ACTION

1^{st}, 2^{nd} and 3^{rd} iteration:

	0.750	0.250	Final
	Compliance	Repairs prog.	Result
PM audits	0.325	0.015	0.248
PM plan	0.221	0.015	0.170
MTBF	0.144	0.029	0.115
WO sys audits	0.073	0.224	0.111
MSI	0.038	0.303	0.104
OEE	0.110	0.083	0.103
CSI	0.058	0.116	0.073
Overtime	0.010	0.166	0.049
Backload	0.021	0.048	0.028

GUARANTEE AN EFFECTIVE ACTION

1^{st}, 2^{nd} and 3^{rd} iteration:

	0.500	0.500	Final
	In site	contractor	Result
PM audits	0.162	0.343	0.252
MSI	0.332	0.074	0.203
OEE	0.227	0.051	0.139
PM plan	0.049	0.227	0.138
MTBF	0.069	0.162	0.116
WO system audits	0.018	0.108	0.063
MTTR	0.108	0.013	0.061
Costs	0.034	0.022	0.028

MAINTAIN A GOOD PREDICTIVE PROGRAM, MAINTAIN A GOOD PROGRAMMED INSPECTIONS PROGRAM and MAINTAIN A GOOD PROGRAMMED REPLACEMENTS PROGRAM

1st, 2nd and 3rd iteration:

	0.500 Planning	0.500 Execution	Final Result
OEE	0.329	0.161	0.245
PM audits	0.012	0.331	0.172
MTBF	0.235	0.082	0.158
MSI	0.041	0.236	0.139
PM plan	0.160	0.115	0.138
Overtime	0.107	0.044	0.076
Cases	0.076	0.015	0.046
BTS	0.039	0.015	0.027

IMPROVE IN SITE PERSONNEL COMPETENCE

1st, 2nd and 3rd iteration:

	0.500 Training	0.500 Right position	Final Result
MSI	0.221	0.224	0.223
OEE	0.030	0.314	0.172
Overtime	0.316	0.024	0.170
MTTR	0.076	0.160	0.118
Applicability	0.164	0.017	0.091
Accidents	0.110	0.032	0.071
CSI	0.016	0.110	0.063
MTBF	0.028	0.077	0.052
Costs	0.039	0.043	0.041

GUARANTEE AN EFFECTIVE IN SITE PROYECT EXECUTION

1st, 2nd and 3rd iteration:

	0.281 Equipment	0.584 Personnel	0.135 Morale	Final Result
MSI	0.044	0.289	0.295	0.221
OEE	0.059	0.221	0.225	0.176
MTTR	0.155	0.121	0.129	0.132
Overtime	0.011	0.159	0.069	0.105
Fill rate	0.286	0.013	0.017	0.090
Cost	0.211	0.030	0.045	0.083
Applicability	0.011	0.092	0.017	0.059
WG status	0.029	0.048	0.169	0.059
Inventory	0.113	0.013	0.017	0.042
Items repaired	0.082	0.013	0.017	0.033

GUARANTEE AN EFFECTIVE PROYECT EXECUTION

1st, 2nd and 3rd iteration:

	0.500	0.500	Final
	In site	Contractor	Result
MSI	0.336	0.143	0.240
Costs	0.051	0.291	0.171
Audits	0.012	0.291	0.151
OEE	0.230	0.051	0.140
Overtime	0.105	0.078	0.091
MTTR	0.164	0.015	0.089
CSI	0.028	0.116	0.072
Fill Rate	0.075	0.015	0.045

DEVELOP COMPLETE ENGINEERING SPECIFICATIONS

1st, 2nd and 3rd iteration:

	0.277	0.122	0.122	0.480	Final
	Manpower	task description	Sketches	Time mgnt	Result
Overtime	0.438	0.129	0.146	0.453	0.372
Costs	0.287	0.085	0.230	0.261	0.243
MSI	0.127	0.440	0.478	0.042	0.167
Accidents	0.085	0.288	0.081	0.024	0.080
BTS	0.018	0.021	0.018	0.145	0.079
Backload	0.044	0.037	0.047	0.076	0.059

CONDUCT APPROPRIATE PRYECT PLANNING

1st, 2nd and 3rd iteration:

	0.200	0.200	0.600	Final
	Tools and spares	Equip. avail.	Engineering	Result
Overtime	0.011	0.317	0.287	0.238
costs	0.210	0.121	0.219	0.197
MSI	0.045	0.071	0.161	0.120
BTS	0.011	0.234	0.089	0.102
Accidents	0.022	0.019	0.123	0.082
OEE	0.058	0.164	0.060	0.081
Fill rate	0.294	0.019	0.015	0.072
MTTR	0.156	0.019	0.015	0.044
Inventory	0.113	0.019	0.015	0.036
Items repaired	0.079	0.019	0.015	0.029

IMPLEMENT IMPROVEMENT PROJECTS

1st, 2nd and 3rd iteration:

	0.500	0.500	Final
	planning	Execution	Result
MSI	0.162	0.320	0.241
costs	0.227	0.243	0.235
Overtime	0.332	0.079	0.206
Contractor audits	0.012	0.166	0.089
OEE	0.052	0.118	0.085
BTS	0.108	0.017	0.063
Accidents	0.072	0.017	0.045
Fill rate	0.034	0.039	0.037

CARRY OUT SELF-DIRECTED INSPECTIONS

1st, 2nd and 3rd iteration:

	0.172	0.100	0.047	0.267	0.414	Final
	Union	Training	Tools & spares	Morale	Time available	Result
Overtime	0.300	0.265	0.014	0.054	0.302	0.218
CSI	0.217	0.218	0.069	0.261	0.201	0.215
BTS	0.118	0.068	0.025	0.131	0.179	0.137
WG status	0.147	0.032	0.043	0.105	0.102	0.101
MSI	0.044	0.171	0.055	0.210	0.035	0.098
OEE	0.081	0.026	0.093	0.168	0.055	0.089
Costs	0.055	0.061	0.223	0.031	0.086	0.070
Fill Rate	0.012	0.012	0.312	0.013	0.014	0.027
Applicability	0.012	0.137	0.011	0.013	0.014	0.026
Inventory	0.012	0.012	0.156	0.013	0.014	0.020

PROACTIVE PILLAR RESULT

1st, 2nd and 3rd iteration:

	0.600	0.200	0.200	Final
	PM	Projects	Self-directed	Result
OEE	0.288	0.084	0.081	0.206
MSI	0.110	0.289	0.106	0.145
PM audits	0.212	0.010	0.012	0.132
Overtime	0.055	0.152	0.284	0.120
MTBF	0.149	0.039	0.039	0.105
Costs	0.021	0.213	0.063	0.068
CSI	0.028	0.032	0.221	0.067
BTS	0.038	0.053	0.168	0.067
PM plan	0.079	0.010	0.012	0.052
Contractor audits	0.021	0.116	0.012	0.038

LOGISTICS Pillar

CONTROL STORES INTEGRITY

1st, 2nd and 3rd iteration:

	0.500 Security	0.500 Auditing	Final Result
Inventory	0.471	0.270	0.371
Audits	0.049	0.497	0.273
Costs	0.274	0.133	0.203
Fill Rate	0.130	0.065	0.098
MSI	0.076	0.035	0.056

IMPROVE PERSONNEL COMPETENCE

1st, 2nd and 3rd iteration:

	0.500 Training	0.500 Right position	Final Result
MSI	0.221	0.224	0.223
OEE	0.030	0.314	0.172
Overtime	0.316	0.024	0.170
MTTR	0.076	0.160	0.118
Applicability	0.164	0.017	0.091
Accidents	0.110	0.032	0.071
CSI	0.016	0.110	0.063
MTBF	0.028	0.077	0.052
Costs	0.039	0.043	0.041

ADMINISTRATE REPAIRS EFFICIENTLY

1st, 2nd and 3rd iteration:

	0.250 Emergency	0.750 Planned	Final Result
Items repaired	0.010	0.316	0.240
Fill rate	0.061	0.217	0.178
Costs	0.041	0.170	0.138
Backload	0.084	0.119	0.110
MTTR	0.339	0.015	0.096
OEE	0.247	0.015	0.073
Inventory	0.029	0.076	0.064
FTT repair	0.053	0.056	0.055
CSI	0.135	0.015	0.045

ENSURE QUALITY OF REPAIR

1st, 2nd and 3rd iteration:

	0.429 Test Equipment	0.143 Procedures	0.429 Labs	Final Result
FTT repair	0.467	0.186	0.301	0.356
Backload	0.147	0.269	0.422	0.282
PM plan	0.258	0.041	0.080	0.151
Fill Rate	0.044	0.404	0.141	0.137
Costs	0.057	0.075	0.034	0.050
OEE	0.027	0.025	0.022	0.025

ADMINISTRATE PART REPAIRS

1st iteration:

	0.195 Personnel	0.073 Equipment	0.463 Repair admin.	0.073 Workshops	0.195 Quality assurance	Final Result
Items repaired	0.061	0.036	0.287	0.329	0.017	0.175
Fill rate	0.028	0.009	0.219	0.101	0.109	0.136
Backload	0.037	0.029	0.116	0.180	0.216	0.119
OEE	0.244	0.182	0.076	0.060	0.065	0.113
Costs	0.010	0.034	0.170	0.036	0.080	0.101
MSI	0.304	0.099	0.032	0.152	0.034	0.099
FTT repair	0.053	0.053	0.048	0.092	0.283	0.098
PM plan	0.010	0.275	0.026	0.008	0.160	0.066
MTBF	0.079	0.275	0.011	0.017	0.027	0.047
Overtime	0.174	0.009	0.015	0.024	0.008	0.045

2nd and 3rd iteration:

	0.195 Personnel	0.073 Equipment	0.463 Repair admin.	0.073 Workshops	0.195 Quality assurance	Final Result
Items repaired	0.061	0.014	0.287	0.325	0.018	0.173
Fill rate	0.011	0.013	0.219	0.103	0.110	0.133
Backload	0.037	0.027	0.116	0.183	0.218	0.119
OEE	0.243	0.283	0.075	0.063	0.049	0.117
Costs	0.016	0.068	0.170	0.038	0.081	0.105
MSI	0.303	0.161	0.032	0.154	0.028	0.102
FTT repair	0.056	0.013	0.049	0.087	0.286	0.097
Overtime	0.178	0.116	0.016	0.027	0.009	0.054
PM plan	0.014	0.089	0.026	0.010	0.157	0.052
PM audits	0.080	0.216	0.010	0.010	0.045	0.046

CONDUCT ADEQUATE PARTS PLANNING

1st, 2nd and 3rd iteration:

	0.500 New	0.500 Repaired	Final Result
Fill rate	0.310	0.237	0.273
Items Repaired	0.018	0.366	0.192
Costs	0.310	0.064	0.187
OEE	0.180	0.101	0.141
Backload	0.113	0.161	0.137
MSI	0.052	0.044	0.048
FTT repair	0.018	0.028	0.023

CONDUCT ADEQUATE PLANNING

1st iteration:

	0.200 Tools	0.200 Machinery	0.600 Parts	Final Result
Fill rate	0.272	0.029	0.291	0.235
Items repaired	0.040	0.059	0.222	0.153
Costs	0.075	0.173	0.170	0.151
MSI	0.123	0.121	0.075	0.094
OEE	0.092	0.027	0.110	0.090
MTTR	0.207	0.018	0.058	0.080
MTBF	0.013	0.229	0.025	0.063
PM	0.013	0.229	0.025	0.063
Accidents	0.153	0.084	0.008	0.052
CSI	0.013	0.032	0.017	0.019

2nd and 3rd iteration:

	0.200 Tools	0.200 Machinery	0.600 Parts	Final Result
Fill rate	0.306	0.040	0.305	0.252
OEE	0.117	0.308	0.113	0.153
Items repaired	0.049	0.031	0.226	0.152
Costs	0.094	0.067	0.177	0.138
MSI	0.162	0.198	0.079	0.119
MTTR	0.227	0.013	0.055	0.081
PM audits	0.015	0.172	0.015	0.046
Overtime	0.015	0.117	0.015	0.035
PM plan	0.015	0.053	0.015	0.023

ENSURE ASSETS IN STOCK

1st iteration:

	0.135	0.584	0.281	Final
	Stores	Planning	Emergency req.	Result
Fill Rate	0.120	0.306	0.228	0.259
Costs	0.166	0.163	0.303	0.203
Items Repaired	0.019	0.227	0.034	0.145
MSI	0.089	0.110	0.056	0.092
MTTR	0.034	0.055	0.166	0.083
OEE	0.015	0.074	0.090	0.071
Inventory	0.312	0.023	0.023	0.062
CSI	0.016	0.032	0.090	0.046
Audits	0.231	0.010	0.011	0.040

2nd and 3rd iteration:

	0.135	0.584	0.281	Final
	Stores	Planning	Emergency req.	Result
Fill Rate	0.120	0.288	0.228	0.249
Costs	0.166	0.120	0.303	0.178
OEE	0.015	0.226	0.090	0.159
Items Repaired	0.019	0.167	0.034	0.110
MTTR	0.034	0.058	0.166	0.085
MSI	0.089	0.081	0.056	0.075
Inventory	0.312	0.019	0.023	0.060
CSI	0.016	0.031	0.090	0.046
Audits	0.231	0.010	0.011	0.040

MINIMIZE HANDLING TIME

1st, 2nd and 3rd iteration:

	0.500	0.500	Final
	Identification	Procedures	Result
WG status	0.532	0.478	0.505
MTTR	0.236	0.278	0.257
OEE	0.137	0.139	0.138
MSI	0.075	0.081	0.078
CSI	0.021	0.025	0.023

MINIMIZE TIME TO OBTAIN THE SPARE

1st, 2nd and 3rd iteration:

	0.750 Near to site	0.250 Quick handling	Final Result
MTTR	0.384	0.257	0.352
Costs	0.252	0.036	0.198
OEE	0.160	0.178	0.165
WG status	0.033	0.404	0.126
Inventory	0.111	0.016	0.087
MSI	0.060	0.109	0.072

ENSURE PARTS EQUIPMENT AND TOOLS AVAILABILITY

1st iteration:

	0.750 In stock	0.250 Prompt Avail.	Final Result
Fill rate	0.358	0.027	0.275
Costs	0.243	0.246	0.244
MTTR	0.067	0.363	0.141
Items repaired	0.165	0.015	0.127
MSI	0.099	0.066	0.091
OEE	0.046	0.174	0.078
WG status	0.022	0.110	0.044

2nd and 3rd iteration:

	0.750 In stock	0.250 Prompt Avail.	Final Result
Fill rate	0.358	0.027	0.275
Costs	0.243	0.246	0.244
OEE	0.157	0.174	0.161
MTTR	0.071	0.363	0.144
Items repaired	0.104	0.015	0.082
MSI	0.046	0.066	0.051
WG status	0.021	0.110	0.043

MINIMIZE NEW MATERIAL IN STOCK

1st, 2nd and 3rd iteration:

	0.500	0.500	Final
	Repairs	Reduce quantity	Result
Fill rate	0.222	0.162	0.192
Inventory	0.023	0.346	0.185
Items repaired	0.311	0.029	0.170
Costs	0.075	0.256	0.166
Backload	0.164	0.066	0.115
OEE	0.107	0.018	0.063
MSI	0.048	0.042	0.045
WG status	0.016	0.052	0.034
FTT	0.034	0.029	0.032

MINIMIZE INVENTORY

1st iteration:

	0.261	0.513	0.076	0.150	Final
	Unification	Minimum new material	Reliable record	Minimum use	Result
Fill rate	0.143	0.290	0.068	0.017	0.194
Inventory	0.242	0.214	0.227	0.017	0.193
Costs	0.331	0.127	0.162	0.047	0.171
Items repaired	0.050	0.166	0.040	0.017	0.104
WG status	0.106	0.074	0.099	0.061	0.082
Stock audits	0.053	0.048	0.323	0.015	0.066
PM plan	0.015	0.012	0.013	0.314	0.058
OEE	0.030	0.044	0.044	0.097	0.048
MTBF	0.015	0.012	0.013	0.208	0.042
PM audits	0.015	0.012	0.013	0.208	0.042

2nd and 3rd iteration:

	0.261	0.513	0.076	0.150	Final
	Unification	Minimum new material	Reliable record	Minimum use	Result
Inventory	0.245	0.211	0.230	0.018	0.192
Fill rate	0.142	0.285	0.061	0.018	0.191
Items repaired	0.046	0.161	0.034	0.018	0.100
Costs	0.335	0.122	0.164	0.087	0.176
WG status	0.104	0.056	0.100	0.036	0.069
MSI	0.038	0.020	0.026	0.190	0.051
Backload	0.021	0.078	0.015	0.069	0.057
PM audits	0.011	0.010	0.010	0.243	0.045
Stock audits	0.033	0.024	0.327	0.018	0.048
OEE	0.024	0.034	0.033	0.302	0.072

PROMOTE PERSONNEL INVOLVEMENT

1st, 2nd and 3rd iteration:

	0.750 Morale	0.250 Awareness	Final Result
MSI	0.309	0.224	0.288
OEE	0.222	0.033	0.175
WG status	0.159	0.023	0.125
Over time	0.036	0.312	0.105
MTTR	0.111	0.073	0.101
Accidents	0.079	0.108	0.086
Applicability	0.012	0.160	0.049
CSI	0.054	0.016	0.044
Costs	0.019	0.051	0.027

MINIMIZE CONSUMPTION IN NON OPERATING HOURS

1st, 2nd and 3rd iteration:

	0.500 Shut down	0.500 Personnel involvement	Final Result
Costs	0.471	0.023	0.247
MSI	0.102	0.360	0.231
WG status	0.264	0.158	0.211
OEE	0.033	0.245	0.139
Overtime	0.033	0.100	0.066
Accidents	0.066	0.046	0.056
MTTR	0.033	0.068	0.050

MINIMIZE LOSSES

1st iteration:

	0.250 Personnel detection	0.750 PM program	Final Result
PM plan	0.014	0.307	0.233
OEE	0.215	0.125	0.148
MTBF	0.028	0.177	0.140
5% Audits	0.009	0.171	0.131
MSI	0.282	0.037	0.098
CSI	0.044	0.079	0.070
WG status	0.159	0.033	0.065
Overtime	0.111	0.037	0.056
MTTR	0.085	0.014	0.032
Accidents	0.052	0.020	0.028

2nd and 3rd iteration:

	0.250 Detection	0.750 Control program	Final Result
OEE	0.217	0.291	0.273
MSI	0.284	0.160	0.191
PM audits	0.013	0.209	0.160
Overtime	0.113	0.108	0.109
PM plan	0.013	0.076	0.061
WG status	0.165	0.019	0.056
Cost	0.029	0.058	0.051
MTBF	0.020	0.043	0.037
Accidents	0.060	0.024	0.033
MTTR	0.086	0.011	0.029

OPTIMIZE ENERGY CONSUMPTION

1st iteration:

	0.429 Losses	0.143 Equipment performance	0.429 Shut Down	Final Result
PM plan	0.332	0.337	0.024	0.201
Costs	0.048	0.041	0.343	0.173
OEE	0.227	0.112	0.132	0.170
MSI	0.068	0.031	0.244	0.138
MTBF	0.162	0.225	0.024	0.112
WG status	0.025	0.012	0.186	0.092
5% Audits	0.101	0.157	0.024	0.076
CSI	0.037	0.085	0.024	0.038

2nd and 3rd iteration:

	0.429 Losses	0.143 Equipment performance	0.429 Shut Down	Final Result
OEE	0.361	0.359	0.113	0.254
MSI	0.245	0.165	0.245	0.234
Costs	0.025	0.047	0.361	0.172
PM audits	0.159	0.244	0.019	0.111
WG status	0.068	0.016	0.167	0.103
Overtime	0.100	0.101	0.077	0.090
PM plan	0.043	0.068	0.019	0.036

LOGISTICS PILLAR RESULT

1st iteration:

	0.637 Available parts	0.258 Inventory	0.105 Energy consumption	Final Result
Fill rate	0.287	0.156	0.019	0.225
Costs	0.212	0.211	0.228	0.213
MTTR	0.156	0.011	0.019	0.104
Inventory	0.040	0.287	0.019	0.102
Items repaired	0.109	0.113	0.019	0.101
OEE	0.057	0.032	0.183	0.064
MSI	0.079	0.011	0.086	0.062
WG status	0.030	0.082	0.096	0.050
PM plan	0.010	0.044	0.299	0.049
Stock audit	0.020	0.053	0.030	0.029

2nd and 3rd iteration:

	0.637 Available parts	0.258 Inventory	0.105 Energy consumption	Final Result
Fill rate	0.311	0.164	0.019	0.243
Costs	0.214	0.222	0.168	0.211
OEE	0.158	0.061	0.318	0.150
Inventory	0.030	0.311	0.019	0.102
Items repaired	0.073	0.111	0.019	0.077
MTTR	0.111	0.013	0.019	0.076
MSI	0.054	0.033	0.227	0.067
WG status	0.039	0.056	0.092	0.049
PM audit	0.010	0.031	0.120	0.027

TRAINING Pillar

DEFINE ON THE JOB TRAINING COURSES

1st, 2nd and 3rd iteration:

	0.600 SKILLS	0.200 PROACTIVE	0.200 REACTIVE	Final Result
FTT	0.419	0.056	0.096	0.282
Accidents	0.290	0.110	0.080	0.212
MTBF	0.104	0.503	0.025	0.168
MTTR	0.104	0.027	0.453	0.158
CSI	0.029	0.235	0.230	0.110
MSI	0.055	0.070	0.115	0.070

DEFINE COURSES APPLICABLE TO THE POSITION

1^{st,} 2nd and 3rd iteration:

	0.391	0.391	0.151	0.067	Final
	Attitudinal	Lesson Learned	On the job	General	Result
Accidents	0.207	0.194	0.301	0.029	0.204
MTTR	0.099	0.204	0.162	0.089	0.149
MSI	0.252	0.019	0.097	0.213	0.135
TS	0.024	0.278	0.023	0.028	0.123
5%Audits	0.159	0.024	0.043	0.016	0.079
CASES	0.018	0.131	0.024	0.244	0.078
MTBF	0.037	0.052	0.202	0.157	0.076
WG	0.114	0.050	0.015	0.090	0.072
CSI	0.077	0.028	0.121	0.028	0.061
COSTS	0.013	0.020	0.011	0.105	0.022

DETERMINE RIGHT COURSE FOR THE PERSON

1^{st,} 2nd and 3rd iteration:

	0.750	0.250	Final
	Applicable	Adequate level	Result
Accidents	0.298	0.019	0.228
MTTR	0.243	0.130	0.215
MSI	0.168	0.183	0.172
Understanding	0.025	0.458	0.134
TS	0.112	0.031	0.092
5% Audits	0.075	0.039	0.066
MTBF	0.050	0.089	0.060
CASES	0.028	0.051	0.034

ENSURE MATERIALS AND INSTALLATIONS APPLICABILITY

1^{st,} 2nd and 3rd iteration:

	0.750	0.250	Final
	Similar Inst.	Course adapt.	Result
Applicability	0.594	0.501	0.571
Understanding	0.121	0.246	0.152
MTTR	0.104	0.104	0.104
MTBF	0.104	0.104	0.104
MSI	0.078	0.045	0.070

USE EXTERNAL MATERIAL AND INSTALLATIONS

1st, 2nd and 3rd iteration:

	0.750 Participation	0.250 Applicable	Final Result
Overtime	0.290	0.014	0.221
MTTR	0.165	0.167	0.166
Backload	0.178	0.014	0.137
PM plan	0.152	0.020	0.119
Applicability	0.030	0.305	0.099
Costs	0.101	0.038	0.085
Understanding	0.013	0.226	0.066
MSI	0.045	0.092	0.056
MTBF	0.025	0.124	0.050

DEVELOP MATERIAL AND INSTALLATIONS INTERNALLY

1st, 2nd and 3rd iteration:

	0.637 Equipment	0.258 Material	0.105 Logistics	Final Result
Costs	0.481	0.076	0.554	0.384
Applicability	0.310	0.440	0.038	0.315
Understanding	0.116	0.265	0.038	0.146
Overtime	0.034	0.154	0.291	0.092
MSI	0.059	0.064	0.080	0.063

HAVE APPROPRIATE TRAINING MATERIAL AND INSTALLATIONS

1st, 2nd and 3rd iteration:

	0.500 In site	0.500 Off site	Final Result
Overtime	0.118	0.335	0.226
Costs	0.350	0.045	0.197
Applicability	0.255	0.066	0.161
MTTR	0.048	0.245	0.146
Understanding	0.186	0.031	0.108
Backload	0.025	0.166	0.096
PM Plan	0.017	0.113	0.065

DEVELOP INTERNAL TRAINER WITHOUT OVERTIME

1^{st,} 2nd and 3rd iteration:

	0.500 Replacement	0.500 No replacement	Final Result
MSI	0.266	0.165	0.216
Backload	0.339	0.022	0.180
MTTR	0.028	0.298	0.163
OEE	0.028	0.298	0.163
PM plan	0.181	0.022	0.101
CSI	0.061	0.136	0.098
Understanding	0.096	0.061	0.079

HAVE PREPARED TRAINERS

1^{st,} 2nd and 3rd iteration:

	0.500 External	0.500 Internal	Final Result
Costs	0.362	0.130	0.246
Overtime	0.032	0.376	0.204
Applicability	0.226	0.090	0.158
MSI	0.091	0.221	0.156
Understanding	0.226	0.066	0.146
Backload	0.032	0.080	0.056
MTTR	0.032	0.037	0.034

HAVE PEOPLE AVAILABLE FOR TRAINING

1^{st,} 2nd and 3rd iteration:

	0.500 overtime	0.500 No overtime	Final Result
Over time	0.445	0.022	0.233
MSI	0.131	0.323	0.227
Backload	0.032	0.230	0.131
Costs	0.226	0.017	0.121
MTTR	0.032	0.164	0.098
OEE	0.032	0.110	0.071
CSI	0.072	0.056	0.064
PM plan	0.032	0.078	0.055

TRAINING PILLAR RESULT

1st, 2nd and 3rd iteration:

	0.500 Right course	0.147 Installations	0.288 People availability	0.066 Trainer	Final Result
Overtime	0.014	0.306	0.313	0.220	0.157
MSI	0.126	0.037	0.225	0.114	0.141
Applicability	0.194	0.159	0.028	0.163	0.139
Accidents	0.246	0.014	0.032	0.010	0.135
MTTR	0.170	0.107	0.089	0.042	0.129
Cost	0.037	0.220	0.120	0.297	0.105
Understanding	0.127	0.082	0.014	0.080	0.085
Backload	0.016	0.055	0.167	0.057	0.068
Troubleshooting	0.069	0.019	0.013	0.017	0.042

PEOPLE Pillar

INDUCE EFFECTIVE BOTTOM UP COMMUNICATION

1st, 2nd and 3rd iteration:

	0.333 Survey	0.333 Meetings	0.333 Personnel suggestions	Final Result
Ideas Implementation	0.274	0.266	0.448	0.329
WG status	0.160	0.381	0.149	0.230
MSI	0.376	0.104	0.193	0.224
CSI	0.034	0.104	0.020	0.053
Cost	0.016	0.066	0.073	0.052
MTTR	0.059	0.034	0.050	0.048
MTBF	0.059	0.020	0.027	0.035
Accidents	0.022	0.026	0.041	0.029

INDUCE EFFECTIVE TOP DOWN COMMUNICATION

1st, 2nd and 3rd iteration:

	0.637 Leadership	0.258 WG participation	0.105 Cascades	Final Result
MSI	0.334	0.206	0.325	0.300
OEE	0.156	0.064	0.146	0.131
MTTR	0.156	0.064	0.146	0.131
MTBF	0.156	0.064	0.146	0.131
CSI	0.084	0.206	0.043	0.112
WG status	0.023	0.332	0.031	0.103
Cost	0.060	0.032	0.146	0.062
Ideas Impl.	0.032	0.032	0.018	0.030

INDUCE EFFECTIVE COMMUNICATION AMONG MAINTENANCE

1st, 2nd and 3rd iteration:

	0.258 Between shifts	0.637 WG meetings	0.105 Union	Final Result
WG status	0.044	0.328	0.073	0.228
MSI	0.292	0.170	0.289	0.214
Ideas	0.014	0.201	0.073	0.139
Accidents	0.049	0.088	0.222	0.092
Backload	0.188	0.033	0.039	0.074
MTTR	0.104	0.056	0.043	0.067
CSI	0.156	0.023	0.039	0.059
PM plan	0.110	0.033	0.016	0.051
MTBF	0.031	0.056	0.016	0.046
Overtime	0.011	0.011	0.191	0.030

INDUCE EFFECTIVE COMMUNICATION WITH OTHERS

1st, 2nd and 3rd iteration:

	0.250 WG meetings	0.750 In site meetings	Final Result
OEE	0.076	0.252	0.208
BTS	0.018	0.252	0.194
WG status	0.392	0.019	0.112
CSI	0.146	0.082	0.098
MSI	0.146	0.082	0.098
MTTR	0.076	0.098	0.092
MTBF	0.076	0.072	0.073
Ideas implementation	0.025	0.082	0.068
Accidents	0.044	0.061	0.057

INDUCE EFFECTIVE LATERAL COMMUNICATION

1st, 2nd and 3rd iteration:

	0.500 Maintenance	0.500 Others	Final Result
WG status	0.307	0.154	0.230
OEE	0.026	0.315	0.171
MSI	0.219	0.088	0.153
BTS	0.010	0.238	0.124
Ideas implementation	0.162	0.030	0.096
Accidents	0.109	0.022	0.066
CSI	0.038	0.088	0.063
MTTR	0.053	0.050	0.052
Backload	0.076	0.014	0.045

INDUCE EFFECTIVE COMMUNICATION

1^{st,} 2nd and 3rd iteration:

	0.333	0.333	0.333	Final
	Bottom up	Top Down	Lateral	Result
MSI	0.171	0.293	0.152	0.205
WG	0.213	0.056	0.284	0.184
OEE	0.027	0.205	0.217	0.150
Ideas	0.288	0.039	0.079	0.135
MTTR	0.070	0.155	0.019	0.082
CSI	0.117	0.083	0.039	0.080
MTBF	0.052	0.112	0.019	0.061
BTS	0.009	0.011	0.108	0.043
Accidents	0.039	0.029	0.054	0.041
Backload	0.015	0.016	0.028	0.020

COMMUNICATE CLEAR OBJECTIVES

1^{st,} 2nd and 3rd iteration:

	0.500	0.500	Final
	Defined objectives	Communication	Result
MSI	0.447	0.371	0.409
WG status	0.026	0.240	0.133
OEE	0.170	0.067	0.118
Cost	0.170	0.024	0.097
MTTR	0.086	0.106	0.096
Ideas Implementation	0.014	0.155	0.085
MTBF	0.086	0.037	0.062

MAKE PERSONNEL BE COMFORTABLE IN THEIR POSITION

1^{st,} 2nd and 3rd iteration:

	0.250	0.750	Final
	training	Right position	Result
OEE	0.044	0.282	0.223
MSI	0.211	0.217	0.216
MTTR	0.080	0.166	0.144
CSI	0.026	0.118	0.095
Overtime	0.293	0.026	0.093
MTBF	0.026	0.087	0.072
Accidents	0.109	0.031	0.051
Applicability	0.161	0.010	0.048
PM plan	0.016	0.042	0.035
Cost	0.034	0.021	0.024

INCREASE EMPLOYEES MOTIVATION

1st, 2nd and 3rd iteration:

	0.166 Clear objectives	0.046 Challenging objectives	0.443 Recognition plan	0.258 Right position	0.087 Compensation	Final Result
MSI	0.282	0.288	0.285	0.225	0.315	0.272
OEE	0.164	0.071	0.093	0.288	0.052	0.151
WG status	0.215	0.137	0.158	0.015	0.028	0.118
Ideas implementation	0.063	0.213	0.197	0.025	0.027	0.116
MTTR	0.086	0.071	0.093	0.163	0.056	0.106
Costs	0.112	0.033	0.093	0.031	0.221	0.089
Overtime	0.017	0.020	0.014	0.109	0.108	0.048
5% audits	0.033	0.038	0.040	0.046	0.018	0.038
Absenteeism	0.010	0.120	0.017	0.012	0.166	0.032
CSI	0.018	0.009	0.009	0.086	0.008	0.030

CONDUCT APPROPRIATE MANAGER SELECTION

1st, 2nd and 3rd iteration:

	0.500 Internal	0.500 External	Final Result
OEE	0.250	0.165	0.208
MTTR	0.250	0.165	0.208
MTBF	0.250	0.165	0.208
cost	0.030	0.374	0.202
MSI	0.133	0.079	0.106
CSI	0.088	0.051	0.069

DEVELOP HIGHLY QUALIFIED MANAGERS

1st, 2nd and 3rd iteration:

	0.750 Good selection	0.250 Training	Final Result
MTTR	0.240	0.067	0.197
OEE	0.240	0.028	0.187
MTBF	0.240	0.028	0.187
MSI	0.078	0.240	0.119
Cost	0.130	0.028	0.105
Overtime	0.018	0.337	0.098
Accidents	0.039	0.107	0.056
Applicability	0.013	0.164	0.051

SHOW INVOLVEMENT BY GIVING THE EXAMPLE (FOLLOWING STANDARDS)

1st, 2nd and 3rd iteration:

	0.750 High morale	0.250 Awareness	Final Result
MSI	0.381	0.229	0.343
Absenteeism	0.225	0.014	0.172
Overtime	0.071	0.331	0.136
Accidents	0.100	0.113	0.104
CSI	0.107	0.023	0.086
MTTR	0.071	0.078	0.073
Applicability	0.013	0.168	0.052
Cost	0.032	0.043	0.035

INCREASE MANAGEMENT INVOLVEMENT

1st, 2nd and 3rd iteration:

	0.510 Leadership	0.072 Walk the plant	0.260 Meeting participation	0.115 Give example	0.043 Prepared managers	Final Result
MSI	0.261	0.344	0.173	0.314	0.118	0.244
MTTR	0.164	0.162	0.087	0.052	0.286	0.136
MTBF	0.164	0.162	0.087	0.052	0.181	0.132
OEE	0.164	0.121	0.087	0.052	0.181	0.129
CSI	0.090	0.069	0.173	0.216	0.036	0.122
WG	0.047	0.052	0.297	0.033	0.024	0.110
Cost	0.057	0.016	0.047	0.026	0.091	0.049
Absenteeism	0.024	0.023	0.028	0.174	0.008	0.042
Overtime	0.011	0.009	0.011	0.060	0.059	0.018
5% audits	0.018	0.042	0.011	0.021	0.015	0.018

PROVIDE EMPLOYMENT PLANNING

1st, 2nd and 3rd iteration:

	0.076 Retired employees	0.513 Right position	0.150 Budget	0.261 Shift coverage	Final Result
OEE	0.357	0.305	0.182	0.244	0.275
MTTR	0.174	0.155	0.059	0.122	0.133
MSI	0.041	0.200	0.018	0.036	0.118
CSI	0.078	0.095	0.028	0.147	0.097
Cost	0.126	0.033	0.300	0.015	0.076
PM plan	0.032	0.027	0.071	0.157	0.068
Backload	0.063	0.053	0.027	0.120	0.067
MTBF	0.017	0.077	0.059	0.065	0.067
Overtime	0.011	0.013	0.241	0.075	0.063
FTT repair	0.100	0.042	0.014	0.019	0.036

PROVIDE WITH A GOOD WORK ENVIRONMENT

1st iteration:

	0.288 O / M ratio	0.147 Healthy	0.500 Safe	0.066 Tools & equip.	Final Result
Accidents	0.045	0.119	0.310	0.069	0.190
MSI	0.201	0.271	0.140	0.095	0.174
CSI	0.066	0.271	0.140	0.024	0.130
Absenteeism	0.021	0.119	0.205	0.013	0.127
Overtime	0.287	0.036	0.035	0.009	0.106
MTTR	0.153	0.089	0.059	0.138	0.096
OEE	0.080	0.050	0.073	0.057	0.070
Backload	0.124	0.025	0.019	0.032	0.051
Fill rate	0.011	0.011	0.010	0.282	0.028
Inventory	0.011	0.011	0.010	0.282	0.028

2nd and 3rd iteration:

	0.288 O / M ratio	0.147 Healthy	0.500 Safe	0.066 Tools & equip.	Final Result
Accidents	0.045	0.119	0.310	0.032	0.187
MSI	0.201	0.271	0.140	0.083	0.173
CSI	0.066	0.271	0.140	0.018	0.130
Absenteeism	0.021	0.119	0.205	0.012	0.126
Overtime	0.287	0.036	0.035	0.012	0.106
MTTR	0.153	0.089	0.059	0.158	0.097
OEE	0.080	0.050	0.073	0.112	0.074
Backload	0.124	0.025	0.019	0.032	0.051
Fill rate	0.011	0.011	0.010	0.311	0.030
Costs	0.011	0.011	0.010	0.230	0.025

PEOPLE PILLAR RESULT

1^{st,} 2nd and 3rd iteration:

	0.452 Motivation	0.158 Management	0.034 Employment planning	0.092 Communication	0.263 Work environment	Final Result
MSI	0.282	0.284	0.170	0.281	0.205	0.258
OEE	0.215	0.112	0.297	0.154	0.042	0.150
WG status	0.159	0.058	0.017	0.207	0.021	0.106
MTTR	0.082	0.217	0.219	0.083	0.059	0.102
Accidents	0.010	0.012	0.015	0.030	0.293	0.086
CSI	0.024	0.080	0.119	0.062	0.157	0.075
Ideas implementation	0.113	0.020	0.010	0.114	0.012	0.068
Overtime	0.056	0.030	0.056	0.015	0.080	0.055
Absenteeism	0.038	0.028	0.027	0.009	0.116	0.054
MTBF	0.020	0.160	0.072	0.045	0.014	0.045

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