# A DECISION SUPPORT SYSTEM FOR PLANNING MAINTENANCE PROCESSES IN A TRANSHIPMENT CONTAINER TERMINAL

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## ABSTRACT

The objective of the research project developed in cooperation with CICT (Cagliari International Container Terminal) is to determine and organize a Decision Support System (DSS) capable of introducing an engineering process of the maintenance activities (emergency and planned maintenance). This system is aimed at representing a useful operating tool for maintenance managers, which assists them in choosing different maintenance policies to take on and also in introducing the management data system, which is interpreted as an essential tool to schedule interventions and, more generally, to manage the resources which form the logistics support system.

In particular, the aim of this paper is to describe the architecture concerning the DSS under construction, the logical-functional relations existing among different modules of which it is made of and to show the first goals achieved up to now.

Keywords: maintenance engineering, decision support system, emergency and planned maintenance, reliability centered maintenance

## 1. INTRODUCTION

The continuous and constant growth of container transport via sea and the many fleet expansions and load capacity increase programmes pursued by maritime carriers in the field, call for the research of new organization methods and new technological solutions for planning and managing all the operating activities performed when handling containers inside a terminal.

Conditions therefore require a greater use of automated systems and new technology to carry out and handle the operations, that ultimately depend on the contemporary efficiency of the handling system in the ship-quay section, of the container horizontal transport system and the stock yard handling system. These tree individual phases, that make up a complete operating cycle, are very closely correlated and performed in sequence inside the port logistics chain cycle and any efficiency failure in one alone of these phases could limit and reduce the performance of the others, causing an operational an operational and overall production loss in a terminal.

Under this prospect the role played by the management of equipment and means of carrying maintenance becomes extremely important, seen as the main process of the "*core business*" performed, and not just a mere element of support. The companies operating in the transport and logistics field, in fact, are ever more oriented towards the implementation of techniques and tools that develop efficient maintenance process planning and management reliability, good function and safety of their systems, together with operating procedures, in order to contend with the ever growing competition of this market.

The elements ruling operational availability of a system are reliability, maintainability and logistical organization of supporting tools (handling spares, maintenance operator training, action scheduling, computer system used for collecting data, data recording and analysis managing outsourced activities, etc.), that allow supplying the required activities within the require scheduled times.

To minimize the overall charge connected to maintenance processes, represented by the sum of direct costs (connected to performing operations) and indirect costs (related to the lack of equipment availability and therefore, to the failure to perform a service), it is actually necessary to identify the most appropriate strategy for optimizing the maintenance policies adopted, choosing the most suitable for each component or subsystem analysed (Buglione 2006).

The role of Maintenance Engineering over the past years is, in fact, the result of the evolution of maintenance from merely reaction forms, enhanced following a break-down/failure, towards ever more sophisticated forms of intervention where concepts and methods typical of engineering techniques have been introduced to obtain improvingly better results in terms of safety, efficiency, effectiveness and costs (Furlanetto, Garetti, and Macchi 2006).

The scope of the development and implementation presently in progress of the DSS described below, is to create a support and control tool capable of, in the same measure as the systems adopted in operating areas for the planning phases of container handling activities and monitoring & reporting (management board), allowing an effective and efficient planning and management of the maintenance interventions performed.

## 2. EVOLUTION OF THE CONCEPT AND THE ROLE OF MAINTENANCE: THE METHODOLOGICAL APPROACH DETERMINED

In the past maintenance has always been considered as a "necessary" cost that "inevitably" had to be supported and therefore had to be minimized while operating a given system (Carpignano and Vivalda 2005).

This kind of concept has determined interventions considered as operating activities for the repair of a system that has failed and requires restoration of indispensable functionality. This kind of old concept has to be overcome in order to introduce a new approach where maintenance is to be considered as a process capable of producing benefits, as an element of the profit sheet on which it be necessary to intervene to improve competitiveness and functionality of the transport system taken into consideration. This scope can be reached creating a system of interventions to prevent the failures or the malfunctions typical to a specific system.

Another fundamental aspect encountered in the transport field, and more specifically relating to the activities performed in a container terminal, is represented by the cultural and technical gap existing compared to other fields of activities, such as industry – plant design, manufacturing and the aeronautical field, in planning and managing maintenance procedures together with the growing importance of the role of maintenance and the overall life cycle of the systems we are considering.

In relation to the different types of production that characterize a company, we can hypothesize three main general organizational schemes designed to obtain, each within its own field, specific maintenance objectives: the matching function model, the radically separate function model, the partly overlapping function model (Pozza 1999).

Thus the requirement to overcome also in the transport field the traditional kind of interpretation becomes obvious together with the necessity to define the relationship and the ties between the two types of processes according to a new and innovative approach that allows reaching a binding integration between operating and maintenance activities, as shown in figure 1 (Naseddu 2008).



Figure 1: Evolution of the role of maintenance processes in a terminal container: from traditional approach to innovative approach

## 3. THE REFERENTIAL CONTEXT: OPERATING AND MAINTENANCE PROCESSES PERFORMED INSIDE A CONTAINER TERMINAL

The technological scenario that characterizes container handling activities, considering the Cagliari transhipment terminal as the field of application, can be described through a three step operating cycle:

- the quay crane picks up the container from the ship at dock using the "spreader". The container is lifted and transferred in parallel to the boom (crane jib) to be then positioned on a trailer
- once this operation is finished the truck trailer, the means of carrying used for horizontal movements, transfers the container to the storage area, corresponding to the destination yard in which it is located
- the yard crane picks up the container from the trailer waiting in a specific aisle and places it in the assigned storage slot. The containers are distributed in given areas within the operating yard

The maintenance interventions performed on the handling systems available and on the equipment used for these operations can be distinct in two different typology:

1. *Planned maintenance:* ordinary routine maintenance managed through a time planned schedule (different deadlines according to types of equipment), performed on various components of the systems in order to maintain functionality. The elements required for

planning maintenance operations are the maintenance repair sheets, the frequency with which the work indicated is performed and any possible malfunction reports indicated by the operators

2. *Emergency calls*: maintenance performed during operations following a call for a technical failure, a non technical failure or an accident in order to restore functional operability of the handling systems /equipment in order to ensure continuity of the operating process

## 4. THE DSS ARCHITECTURE

The DSS architecture consists of four modules or sub-system (Sprague Jr. and Watson 1993):

- the *data base*, which splits into two elements: a "static" data bank which is a simple subsystem used for ensuring a detailed collection and accurate recording of all the information associated with the operations performed; a "dynamic" data bank which allows subsequent data analysis and statistical elaboration
- the *model base*, which consists of various submodels which are used for describing and examining the quantitative and qualitative aspects concerning functionality, reliability and operating costs of the quay crane (F.M.E.C.A - Failure Modes, Effects and Criticality Analysis, a modelling approach to examine and to analyse the reliability and the availability of complex systems, total cost function associated with different maintenance policies adopted, integration between maintenance and spares managing procedures)
- the *evaluation model*, which is distinguished among various sub-models used to define the appropriate techniques through which the different alternative strategies are assessed
- a *dialog system*, link element between the user and the same system, represents the external image through which it can operate

DSS set up in this manner represents the specific tool which allows to build and test various possible scenarios through the integration and the contemporary evaluation of:

- technical aspects: maintenance policies and strategies adopted
- operational aspects: planning operating procedures
- management control and cost controlling: budget, forecast and balance analysis
- management procedures and optimization of spare parts stored in the technical warehouse
- improvements, technical changes made to equipment and investments

 human resources management: managing maintenance teams, outsourced activities and supplier management



Figure 2: An overview of logical-functional DSS architecture

Analysis of the existing scenarios and simulation of future possible scenarios represents the active and most important component of the entire system, allowing the development of a DSS capable of being used as an effective tool to assist maintenance activities planning.

The data pre-processing activity is an intermediate sub-module located between the data base and the assessment module and it is a fundamental part required to adequately select, transform and handle the information associated with emergency calls and planner maintenance that will be collected and recorded.

The preparation of a similar support tool, so that it completely and effectively satisfies it scope, should be accompanied by an engineering process of all maintenance activities and by the introduction of Maintenance Engineering as a company function. In fact, the use of reliability, management and organizational type analysis principles, methods and techniques, allows a company to manage maintenance in a scientific engineering principle based manner.

The approach method chosen for this scope is to develop R.C.M. technique in order to concentrate

maintenance planning interventions on the reliability study and analysis of the complex quay crane system, in compliance with a procedural scheme developed in 5 fundamental macro phases:

- formation and training: active involvement and participation of the maintenance teams. "The best maintenance programme is one which can be effectively used... It needs to take a proactive form in which maintenance personnel can use it to perform the work efficiently and effectively" (Bello 2005)
- 2. creating a specific Maintenance Information System
- 3. functional breakdown of the quay crane system into sub-systems to be analysed separately, as shown in figure 3
- 4. setting-up the F.M.E.C.A analysis
- 5. determining maintenance requirements and choosing the most appropriate strategy for each subsystem individualized

These different phases, determined to optimize all the resources employed, should be supported by the introduction of specific engineering parameters where the reciprocal relations (reliability, availability, maintainability) can be modelled, and by the definition of a cost function associated with the maintenance policy adopted, in order to dispose of the most adequate tools for a correct comparison and the consequent choice of the most efficient and effective strategy.



Figure 3: Quay crane functional breaking down

#### 4.1. The Data Base structure

The Data Base module has been set up in order to represent an actual Maintenance Information System, not just a simple information file. Introduction of this module is an indispensable tool which allows for a detailed and effective recording of the interventions performed and a guaranteed analysis of the criticalities and performances based on the maintenance strategies adopted. It is characterized by:

• a *static* component, that is the archive in which all the information collected after an emergency call and/or an ordinary maintenance work (work sheet) performed on the quay cranes, are recorded and sorted

dynamic component, that has been а introduced as a tool to combine the various static data elements subsequently used to compose different models. This second submodule is the fundamental element within the logical-functional structure of the DSS that is being implemented, because if the designed system is to completely and exhaustively satisfy the functions for which it has been created, availability and correct handling of the information is indispensable for the subsequent phases of analysis and assessment. For this reason the module has to be very versatile and capable of dialoguing with the static data base and the base model, in a continuous and reciprocal exchange of outputs

The method of collecting and recording the information related to the maintenance activities performed, that correctly treated and indicated represent the data for subsequent development (Base Model), can be distinguished in:

- computerized management of emergency calls and programmed maintenance (as shown in figure 4)
- F.M.E.C.A. analysis, both quantitative and qualitative. It is performed to systematically evaluate mode, cause, mechanism and effect of each type of failure determined. In this way it is possible the correctly evaluate the level of criticality of the system being observed (Furlanetto, Garetti, and Macchi 2007)
- dedicated questionnaires to be filled in by the people responsible, the coordinators and the maintenance operators
- regular tests performed contemporarily between technical areas and operation areas (information reports)
- shared computer tools and applications for a technical-operational equipment management



Figure 4: An application of the Computerized Maintenance Management System (CMMS)

## 4.2. The Model Base structure

The Base Model is divided into 4 different sub-models (of which the first and the second are in a advanced phase of developing), through which it is possible to analyse the maintenance management and planning issues by combining together all the most significant operational-engineering variables and the cost and spare parts management methods:

- reliability model, the construction of which strongly depends on the accuracy and detail of the recording of all failures and the time required for repair. In fact, from this information it is possible to formulate a reliability rule of the system whose improvement or maintenance within certain values represents a decisive tool for obtaining a greater availability of the quay crane. Main reliability engineering tools are: accurate failure data for making good decision, reliability indices like MTBF, probability plots, bathtub curves (Barringer 1996), which are described in detail by (Smith 1993) and (Moubray 2001) and regarded one of the basic tenets of reliability engineering. By using reliability analysis quantitative methods and analytic techniques, such as simulation of discrete events, Monte Carlo simulation and genetic algorithms it is also possible to simulate the behaviour of the system under identified conditions and thus verify if the solutions implemented to increase reliability are actually reaching the expected results. In particular, the Monte Carlo method is a powerful modeling tool for performing realistic reliability and availability of complex systems (Merseguerra and Zio 2002). In this way it is possible to compare the various maintenance organization and planning scenarios with the scope of reducing emergency call work and increasing ordinary type maintenance interventions with scheduled equipment break-downs based on the operating area production requirements (close integration between operating processes and maintenance processes)
- maintainability and logistic organization support model, with which it is possible to determine the methods required to increase availability of a complex system, such as the quay cranes, by appropriately evaluating both the intrinsic attitude to maintenance (ease of intervention, accessibility, etc.) and the logistic support management (size of the service, support equipment, maintenance plans, efficiency of spare parts management, maintenance team management, etc.) upon which it be necessary to act in order improve the organization of maintenance intervention schedules (Chiesa 2007). These two variables

represent two important competitive levers to work upon in order to reduce equipment down times that cause unavailability of the cranes. Another interesting application of the model, under development, presently is the representation and analysis of the close tie between maintainability, safety and human factor aspects, associated with performing emergency call interventions. The approach adopted is based on the construction of a general critical index, that was associated to the different sub-systems of which the complex system such as quay crane is made of, through the analysis and the match of quantitative and qualitative aspects concerning maintenance process which have been extracted by means of the exhaustive survey data about emergency calls and maintenance operator's task

- availability model,, with which it is possible to measure the availability of the quay crane system compared to the requirements set forth by operations area for its employment in container handling activities, in consideration of the great flexibility of employment required for this equipment in relation to planning ship operations. Furthermore, measuring availability allows to evaluate the level of service the system has reached and to quantify, in terms of lack of production, the value of loss of availability
- *cost model*, the specification of a general cost function (1), to be related with a given maintenance strategy, has the scope of evaluating the total costs sustained and researching the most effective technical-organizational solution for reducing them, by optimizing the available resources (human resources, spare parts and stores, financial resources and investments) and reducing any costs tied to the non availability of the crane (failure to provide the service):

 $C_{tot} = C_{human resource} + C_{stock} + C_{financial} + C_{failed output}$ (1)

## 4.3. The Evaluation Model structure

The structure that distinguished the evaluation model can be outlined as described in Figure 5.

The type of algorithm used to compare the different maintenance policies, depending on the crane components or subsystems taken into consideration and based on the level of detail chosen, depends on the kind of analysis performed and on the type of intervention required. Through one-scope analyses such as costbenefit, it is possible to estimate the monetary value of a part or all the modelled variables (reliability, maintainability, logistic support, availability) by associating each one, if feasible, to a cost and then be able to compare the total costs of two different strategies or organizational models and thus choose the most effective and efficient one. While with multi-scope analyses it is possible to overcome the difficulties tied to any monetary evaluation that finds place in the system to describe the maintenance processes taken into exam and it is possible to develop general indexes to compare two or more management methods. The final choice of the algorithm obviously depends on the requirements of the decision maker (maintenance responsible and company management) and by the level of analysis desired.



Figure 5 : Evaluation model structure

## 4.4. The Dialog System structure

The Dialog System is the interface between the entire system with the user. It is the component with which the user operates to take advantage of all the various functions and applications the DSS can perform. Its main characteristics should be user friendly, high flexibility and capability of supplying effective and thorough reports, while elaborating performance indicators, responding to the various levels of detail required.

Its 4 main sub-modules are (Fadda, Meloni, Cherchi, and Fancello 1997):

- *Knowledge base*, which contains all the systems required by the user to get the information he needs, in either number or text format
- Action language, which includes all the various systems which enable to act directly on DSS by performing a physical action, such as using a mouse, a keyboard, or a screen (for example employing touch-screen or vocal system solutions)
- *Presentation language*, which collects all the systems that record information in the data base and their subsequent elaboration using the various models present in the base model
- *Dialog system*, which consents interaction and creation of the reports required by the previous sub-modules and their employment by the user, creating a single language that allows access and communication with DSS and an effective interaction man-machine thanks to its modular structure

#### 5. CONCLUSIONS

The introduction of a Decision Support System, in this context and with this above mentioned rationale, becomes an essential tool for maintenance managers to obtain, through the close link of all sub-systems that form its structure:

- the detailed and efficient recording of the interventions performed
- the analysis of criticalities and failures involving the quay cranes
- the evaluation of guaranteed performances based on the maintenance strategies which are adopted and compared

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During the period from 1989 to1991 he also taught the course on Transport Planning at Cagliari University and for the 1992-1993 academic year he was professor of Transport Planning at University of Genova.

He has authored numerous books, papers, treatises and articles on transport-related issues and has been granted patents in the area of urban public bus transport.

From September 1994 to January 1998 he was regional councillor for Public Works for the Sardinian Regional Government. He also served as government vice-commissioner for *Water Emergency* during the period 1995-1997. From 1998 to 2004 he was a member of the scientific committee of the Public Works Superintendency of the Friuli-Venezia-Giulia regional government.

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