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Geraerds, W.M.J.

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The EUT maintenance model

W.M.J. Geraerds

Eindhoven University of Technology, Eindhoven, The Netherlands

Abstract

Since the end of the sixties attention has been paid to the fundamentals of maintenance and to maintenance management in courses and in research at the Department of Industrial Engineering and Management Science of the Eindhoven University of Technology. The descriptive model, which is generally valid, was developed in order to illustrate the interrelations of partial and dispersed knowledge. Its usefulness is not limited to academic activities; it also serves as a tool to assess possibilities to improve maintenance in an enterprise. The structure of the model is explained in this article.

1. Introduction

In the late sixties maintenance was introduced as an elective in the MSc curriculum in Industrial Engineering at the Faculty of Industrial Engineering and Management Science at EUT (Eindhoven University of Technology). Students can choose an elective course with the specific intention to concentrate their final MSc research project on that area. Over a hundred by now made use of that option, carried out through research in practice, not behind the desk. Research started at the beginning was explorative by nature. It appeared impossible to evaluate the abundance of publications as for the relevance of their specific contributions to maintenance science. The advocating of the – hardly turning up in practice – bathtub curve was not followed by the consequential conclusions how to act differently. The endless stream of statements that preventive maintenance “is good for you” did not specify how to determine what preventive maintenance was to be carried out. The majority of publications on the economic aspect suggested that maintenance costs were too high anyway, and that all that was needed was to realize maintenance at optimal costs, again not specifying the way in which that would be achieved. It soon became evident that for a systematic approach a functional framework describing maintenance was needed. Therefore attention was paid to develop, gradually, a model. The eventual result is presented in this paper.

2. Model, necessity and limitations

A model is a – partial – representation of reality. A complete, and true representation of reality would be possible only by a completely identical copy of it. That, as a matter of fact, is not a feasible idea really. Some problems can be solved by research and experimentation in actual situations, but not all, because the actual situation often does not permit to carry out the experiments required.

First of all the time required to carry out an experiment can be prohibitive. It takes time before a foregoing policy has disappeared from results turning up and before the new policy has phased in completely. It is not until that time that the period of evaluation of the difference in results can start. Evaluation of an alternative policy may, consequently, very well require one to two years. If more than one alternative policy has to be compared each alternative requires successively its own period of application and evaluation, as simultaneous investigation is impossible. Therefore experiments of this type in real situations are essentially impossible.

Secondly, setting the limit of the value of es-
sential parameters sometimes requires assessing the fatal limit by experiment. In real situations that would require passing the fatal limit, which in some cases would result in economically unacceptable, if not calamitous, consequences.

Thirdly, real situations are complex. If scientists (or consultants, or managers) use the term complex they actually often hide that they do not really understand the issue concerned sufficiently. However, specific problems turning up and requiring an answer in practice usually have a limited scope. There can be no doubt about it, then, that if we still do want to make progress by analysing alternatives, even if the problem is "complex", we have to release the unattainable intention to cover all possible questions, which could turn up in respect to a specific function, maintenance in this case.

Another reason to design the model is the need to be able to describe maintenance in general, independent of but covering the diversity of individual situations. The way in which general models are designed is predominantly determined by the specific intention of the model designer with respect to the problem he wants to attack. In the present case the objective to illustrate maintenance as an interrelated set of processes to be managed prevailed, corresponding with the industrial engineering approach of organizations.

Taking this into account, a model with its limitations is a suitable tool to look into real situations for the possible aspects which are taken up in the model in view of the objective.

3. Model usefulness

The intended use of the model is plural:
- On the academic level it serves as an instrument to inventory in a systematic manner:
  - available scientific knowledge against lacunae in that knowledge, thus indicating to which problems further research should be directed;
  - the knowledge available in each of the interrelated subfunctions, assisting students in understanding the relationships in the diversity of isolated pieces of knowledge they have collected, in particular where the applicability to the maintenance situation is not explicitly apparent to them, because it was presented under a nonmaintenance heading.
- In practice it serves as an instrument for maintenance management in the systematic identification of:
  - subfunctions in which knowledge, available but not applied yet, provide possibilities for improvement;
  - the subfunctions which are corresponding with "cost centres", in order to provide a basis for their evaluation in respect to effectiveness and efficiency.

4. Starting points for the EUT-maintenance model

The following starting-points underlie the model:

(1) Industrial engineering

First of all the model is based on the principle of the view of industrial engineering on an organization. This essentially comes down to regard an organization as an interrelated set of processes, the output of which can, and must be, influenced by planning and control. This requires the contribution of several scientific disciplines, an approach known as "multidisciplinary", in which systems theory and operations research play an important role, but concern two of the disciplines involved only.

(2) Universal

The model should be universal in view of the technological diversity in practice of objects to be maintained. It should cover not only production equipment, but also buildings, roads, ships, etc.

(3) Organizational variations

The model primarily concerning maintenance as a function within an organization should not exclude contract maintenance provided by general contractors, or as product support by the original equipment manufacturer (OEM).
(4) Feedback to design

Not going into the process of designing technical systems as such, the model should include the feedback of information to the design methodologies of the various technical design disciplines.

(5) Disposal

It was not considered to be required to take up the disposal phase. It is taken up in the UK terotechnology model and in the US life cycle approach, however they concentrate on the life cycle phases of one technical system only, not on maintenance as a function in an organization. The individual decisions about the disposal of a technical system, as well as decisions about the introduction of new technical systems and about their replacement do not belong to the core of maintenance theory. It actually concerns investments considerations which can be handled by well established methods for replacement decisions.

5. The structure of the model

The model specifies the subfunctions, or subprocesses, connected by their interrelations. The model primarily shows maintenance as it appears in an organization, seen from the point of view of maintenance management. The organization is supposed to have its own maintenance department, making use of contractors and of product support by the OEM (Original Equipment Manufacturer).

The model, depicted in Fig. 1, contains the following subfunctions:

(1) the objects (TS's) to be maintained (TS = Technical System);
(2) the internal capacity;
(3) the external capacity offered in the market by a diversity of contractors;
(4) the external capacity offered specifically by the OEM's (Original Equipment Manufacturer);
(5) maintenance planning and control;
(6) the inventory control of nonrepairable maintenance parts (consumables);
(7) the maintenance planning and control of rotables;
(8) the evaluation of results;
(9) the terotechnical feedback;
(10) the methodology of design of a TS;
(11) the specification of requirements for a TS;
(12) the design of a TS;
(13) the manufacture of a TS;
(14) the design of the maintenance concept for a TS.

It should be mentioned that the model does not include maintenance technology. Maintenance technology is – analogous to chemical technology, mechanical engineering technology, and such like – a collective noun for the very diverse collection of technical maintenance operations. Up to a high degree they are directly derived from manufacturing technology, partly they are specific for maintenance, such as corrosion control and repair welding. Maintenance technology is outside the scope of industrial engineering, it belongs to the field of responsibility of the technical disciplines, and consequently is outside the scope of this paper.

6. The subprocesses distinguished

In the two bands at the bottom of the figure the upper band indicates the subfunctions which are taken up in the figure over the band. The lower band indicates which of the subfunctions concern the contributions to be obtained from the technical disciplines, and which subfunctions concern the field of interest of industrial engineering.

In the following Sections the subprocesses will be described briefly.

6.1 The technical systems (TS's)

The diversity of objects to be maintained in an organization using them shows enormous diversity, e.g. lathes, elevators, compressors, the illumination, the copiers, the washrooms, the office of the executive managing director and the wordprocessor used by his secretary, means of transport (such as: cars, trucks, busses, aeroplanes, railway carriages, locomotives, forklifts, bicycles, cranes, ships, conveyors, etc.), telex, fax, telephone, the telephone exchange, roofs, the
Fig. 1. EUT maintenance model.
central heating system, the buildings, the parking place, roads, robots, the flowerbed in front of the head-office (and in front of the maintenance manager's office, if applicable), computers, the NC-controlled machines, the canteen, etc.

This diversity is allowed for in the model by indexing the TS's from 1 to \( n \). It indicates that we have quite a number of TS's, but also and in particular that that collection of TS's is known (or, if not, should be) exactly in an organization. The eventual collection was determined as a result of the decisions that were made about the introduction and the disposal of the TS's.

The model shows one box for technical system 1, 2 and \( n \), each, whilst technical system \( i \) has 3 boxes. This corresponds with the case that more than one, a group, of identical TS's are used. This distinction is very important, because planning and control of the maintenance of a singular TS differs substantially from the case of a group of identical TS's. While planning and control of maintenance of singular TS's can, essentially, be derived from production planning and control theory, identical groups open up possibilities which are typical in their own right for maintenance. We confine ourselves in this article to the reference to some relevant literature \([1-3]\).

6.2 The internal capacity

The internal capacity is the capacity which is a part of the own organization, i.e., of the payroll. It has to cope with the total maintenance load minus the maintenance contracted out. Given the total maintenance load the primary strategic decision to be made is what maintenance will be contracted out. That issue will be treated in Sections 6.3 and 6.4.

The following decisions about the internal maintenance capacity primarily concern how to structure the total capacity in organizational capacity groups. Typical aspects to be taken into consideration are e.g. centralization versus decentralization, technological trade groups versus groups with specific plant units or TS's, monoskilled versus multiskilled mechanics. Once the structure has been established the workforce for each organizational unit has to be established. Conventional work study methods provide the tools for the assessment required. The capacity groups distinguished are denoted by the index, 1, 2, ..., \( j \), ..., \( m \), again indicating that the total capacity is known. It includes the maintenance contribution which is supplied by operators or "production".

6.3 External capacity, offered in the market

External maintenance capacity can, up to quite some extent, be obtained from enterprises offering their services, because they dispose of the technological capability, the experience and the tools required. In some cases this may concern a technology which they primarily offer, and consequently keep up to the mark, in the production of new systems, but which is at the same time the appropriate technology for maintenance, e.g. painting, or roof maintenance. In other cases it can concern a specialized and advanced technology, such as oil analysis. Making use of those external services is interesting for organizations for two reasons.

First of all it may not be economically feasible to maintain the technological capability in house, because the demand for it is too low for a regular workload. (Specialistic contracting out). Secondly, maintenance, which the organization is capable to carry out itself technically, may show peaks in the demand which occasionally exceed the internal capacity available. It is attractive then to contract out the incidental peaks in maintenance demand. (Capacity contracting out).

In addition other considerations may play a role, e.g.:
- transfer of the responsibility for correct and timely execution to somebody else;
- transfer of liability in respect of safety and the consequences of accidents;
- focussing the available internal intelligence on the primary process of the organization;
- the possibility of, temporarily, taking back work contracted out in case of a recession, thus releasing the problem of overcapacity.

There is an increase in the number of enterprises which offer maintenance services. Often it is difficult to specify clearly, and verifiably, what exactly should be carried out. Therefore maintenance is increasingly offered together with standardized contracts.
6.4 External capacity, offered by the OEM's

As was remarked in Section 5 maintenance operations, in the end technological in nature, are consequently up to a high extent derived from manufacturing technology. Enterprises which manufacture and sell a product do possess the design engineering knowledge and the technical skill, know-how and tools required to manufacture that product. If that capability can also be applied in the maintenance of the product, offering maintenance as a service becomes feasible. The advantage of the OEM (Original Equipment Manufacturer) over possible competitors is evident. In some cases the user can choose if, and up to what extent, he will make use of the services offered. In other cases, however, he has no choice. This is due to the fact that the OEM does not provide essential information, such as technical manuals, spare parts lists and engineering support, and does not supply spare parts if ordered. It is evident that the user, who selected that supplier, is completely dependent on him. As competition is out, it is obvious that the OEM considers his service department as a profit centre. This will result in a price which will include an additional profit charge of, say, 20 to 30% over the actual service costs. It is evident that the purchaser of a product has to consider this at the time that he makes his purchase decision. That requires that that decision is not based on performance and acquisition price only, but on life cycle cost considerations. It should not be forgotten that the euphemistic term “service” is a product which is sold with the eventual objective to make a profit.

6.5 Maintenance planning and control

Maintenance planning and control concerns the intervention through which the eventual result of maintenance operations corresponds with the established objectives. In correspondence with the analogy with production planning and control [3] we distinguish:
- planning;
- work preparation;
- control (of maintenance execution).

Planning has to set the standards required in the control of the actual execution of maintenance. Production control theory provides solutions applicable in maintenance, in particular models which appeared suitable in what is known as the “job shop”. Network planning is applicable in major maintenance jobs, such as a maintenance shutdown in process industry or an overhaul. Still, network planning, as far as developed, requires further study for application in maintenance in view of the uncertainty which is typical in maintenance. Batch production models are applicable in maintenance, however, that is limited to the central specialized workshop in which the maintenance to be carried out concerns a technologically limited assortment of products, e.g. electrical or hydraulic components turning up with a relatively high demand.

Work preparation in maintenance is much more complicated than in production because of uncertainty, as well as for the actual maintenance operations to be carried out, as for the estimation of the operation time, as for the assessment of the parts required for each job. Operation time estimation also requires a different approach, coming down to a simplified method, such as UMS (Universal Maintenance Standards), derived from the micro systems developed for operation time estimating in production control.

Control of maintenance execution is directly connected to the planning system, which sets the standards which control has to meet in the actual realization. Understanding that relationship, therefore, is an essential prerequisite for application in maintenance.

6.6 Spare parts inventory control

Waiting for parts is a well-known nuisance in maintenance. This concerns first of all small and cheap parts (“nuts and bolts”) of which the demand is relatively high. They are known as “consumables”, i.e., nonrepairable parts, which requires that their consumption must be followed by acquisition through procurement by means of the inventory control system. In inventory control theory ample SIC models for inventory control have been established. They are based on statistics (SIC=Statistic Inventory Control), which requires that the demand is high to rela-
tively high. However, in maintenance, far the majority of items show a low to very low demand indeed [3], and their price is usually high, leading to high investments. Though the high demand items can be controlled by the conventional SIC methods, the dominant issue lies with the items, i.e. the majority in the assortment, of which the demand is low [4].

6.7 Inventory control of rotables

Rotables are components, usually assemblies, which can be taken out of a technical system, and can be built in again after restoring them to the operable state. Holding spare components in stock makes it possible to replace the inoperable component by one out of the stock, thus eliminating the time that the technical system would have to wait till the component which was built out has been maintained. The inventory of spare rotables will have to be controlled. However, this concerns primarily registration of the issues, and secondly the re-ordering of additional components in case components are damaged beyond repair (for technical or economic reasons). Normal replenishment requires maintenance. That maintenance requires planning and control, which is part of the maintenance function, and which is outside the scope of inventory control.

6.8 The evaluation of results

Planning and control systems require continuous performance evaluation in order to assess when adaptation or improvement is required. The evaluation concerns a diversity of possible aspects e.g. costs, failure rates, down times, etc. and different measuring intervals may be used. The evaluation can lead to corrective measures, such as modification of the technical system concerned, adaptation of the maintenance organization, adaptation of the maintenance concept of a technical system or adaptation of the way or the situation in which a technical system is used.

6.9 The terotechnological feedback

Some of the modifications which appear attractive may be too expensive for technical systems which have been manufactured already. However, the findings can be fed back to the methodology of design, in order to make use of them when new technical systems are designed. The purchaser of new equipment can make use of them in the specification for design or for selection of new equipment.

6.10 The methodology of design of a TS

Observing how technical systems are designed one can notice different approaches in the various technical disciplines. Methods differ from a simple checklist, typical in mechanical engineering, to advanced process and functional analysis, typical in aeronautical engineering. This is out of the scope of industrial engineering.

6.11 The specification of requirements of a TS

The specification of requirements of a TS which has to be designed and manufactured can be determined by the purchaser. In addition to the usually performance oriented requirements specific maintenance requirements can be taken up. They should also include technical manuals and the product support expected.

If it concerns technical systems to be selected from the assortment offered in the market the specification of requirements for design and manufacturing was determined by the manufacturer. In practice we see substantial differences in the attention that was paid to the maintenance aspect. Therefore the purchaser has to determine his own specification of requirements, to serve as criteria in his eventual selection from the assortment offered by the market. It is evident that the maintenance manager should be involved in the specification of requirements from the point of view of maintenance.

6.12 The design of a TS

The actual design of a technical system concerns the technical disciplines involved. Consequently it is outside the scope of industrial engineering.
6.13 The manufacture of a TS

This also is outside the scope of industrial engineering. However, some failures may be due to shortcomings in quality control of the manufacturing process. Maintenance evaluation may lead to specific requirements regarding the manufacture of a technical system.

6.14 The design of the maintenance concept for a TS

A key question in maintenance is: “how much maintenance is enough”. That question can be answered only by a systematic approach, based on the failure behavior of the technical system concerned. This was a research topic at the Eindhoven University of Technology for many years, in which the term “maintenance concept” was introduced as the ordered set of rules, which prescribes what maintenance activities should be carried out when with relation to a technical system. The eventual result was a framework for the design of the maintenance concept of a technical system, presented in a Ph.D. thesis [5], followed by a series of tutorial publications [6–9] and a publication on one of the applications [10].

The maintenance concept of the technical systems in use, together with their operation intensity, determine maintenance demand for the set of technical systems in use of an organization, bringing us back to the technical systems introduced in Section 6.1.

References