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ECONOMICAL ASPECTS OF TOOL LIFE IN COLD FORGING

P. F. Bariani*, G. A. Berti*, L. D'Angelo*, M. Marengo° and M. Vianello*

* DIMEG - Department of Innovazione Meccanica e Gestionale, University of Padova
° TEKSID - Divisione Componenti Acciaio SpA, Turin.

Abstract

Due to the increasingly large investments requested for tooling and equipment, the cold forging technology keeps its levels of competitiveness on the condition that a deep exploitation of the tooling systems is achieved and forging machines are kept in operation as much of time as possible.

The purpose of this research work is to evaluate the importance of the service life of components in the tooling systems with respect to production costs. Alternative tool maintenance and replacement policies are presented and discussed together with the techniques for their simulation and evaluation. The effects of the implementation of preventive maintenance strategies extended to the overall tooling system are highlighted in terms of equipment downtime and manufacturing costs.

1. Introduction

The growing level of complexity in cold forged parts together with the request for shorter delivery times represent two main factors that companies face with. In response to these, major efforts were focused in recent years on a continuos improvement of manufacturing quality and increasing productivity, keeping production costs at relatively low levels.

Because of their intermediate position between the product and the forging machine, tool elements must be properly designed and manufactured with a view to guaranteeing that the machines' capabilities are fully exploited and that the potential levels of productivity and quality are attained [1].

In cold forging tooling costs usually account for 10 to 40% of the total manufacturing costs and investment analyses revealed a constant growth in the levels of capitals tied up in tools. Costs for the first tooling system to produce a new forged part are usually determined by:

- tool material cost and
- labour content for tool fabrication,

the latter contribution including man hours for machining, grinding and polishing [2]. However, tooling costs are to be considered not only in terms of initial cost for the manufacturing of the first tooling system, but also as costs for tool maintenance and replacement.

The focus of this work is on the effects of tool components life on production costs and their evaluation. The first part of the paper is mainly concerned with methodological aspects of the problem, whereas the second part presents some results. Alternative tool maintenance and replacement policies, together with their effects on production costs are discussed, as well.
The study is based on data from machine-tool manufacturers and the toolmaking department of a forging company.

2. Maintenance Costs and Policies

2.1. Tool Life and Maintenance Costs

Different causes such as wear, fracture, surface welding and plastic deformation can lead to the malfunction or break down of tool components.
If compared with the production volumes, these tools have rather short service lives, this term referring to the number of identical subsequent forming operations that can be processed by a single tool (or tooling system), ensuring at the same time the required product quality. Further, it is known that there is enormous scatter of tool lives for the same tool design and tool layout [3]. A number of studies [4, 5] pointed out that tool lives are scattered according to the Weibull function [6]. Hence, the behaviour of a die set performing a given operation on a given material can be characterised by the Weibull constants. These constants are:

- η, describing the tool characteristic lifetime, and
- β, the shape-determining constant, which is representative of the life scatter.

A typical life distribution for components in cold forging tool die set is shown in Fig.1. The problem connected with a preliminary estimation of tool life is evident.
According to their respective service lives, a number of tool components has to be replaced during the production of a cold forged part. Maintenance costs occur each time a tool replacement is required: as a tool fails, the press has to be stopped and the tool block partially disassembled in order to replace the failed tool element. Correspondingly, maintenance costs are the result of three different contributions:

- Tool Costs,
- Downtime Costs and
- Assembly Costs.

The first contribution refers both to material and labour content required to manufacture the tool component.

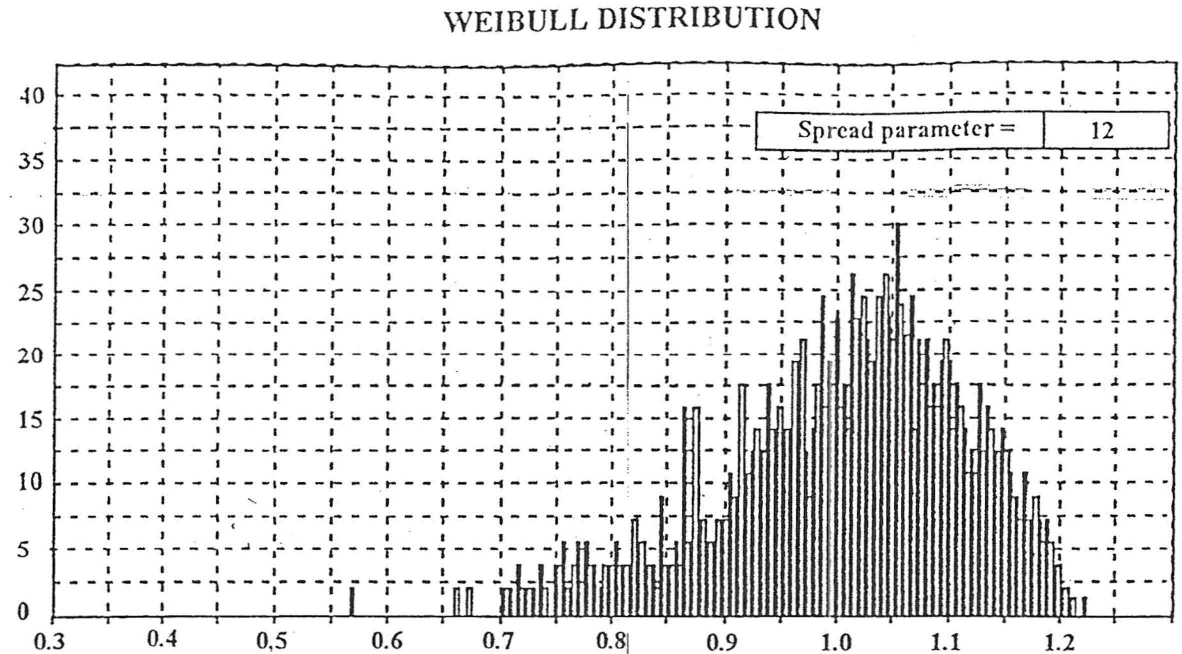


Fig. 1. Typical life distribution for a cold forging tool component. (output of a SIMSCRIPT simulation)

Downtime Costs are incurred due to the press idle time, that is the time required to disassemble/assemble the tooling system and replace the failed tool element.

The last contribution refers to operations usually performed off-line and consisting in pre-stressing the die element through the assembly of one or more stress rings. Several hours can be necessary to complete these operations.

2.2. Maintenance Policies

An increasingly large investment in tooling and equipment is required to cold forging organisations. Hence, basic requirements to make the technology competitive are achieving a deep exploitation of the tooling system as well as keeping the forging machine in operation as much of time as possible. An appropriate and well planned tool maintenance policy can lead to a good trade-off through minimising costs of machine downtime and tool replacement [7].

The majority of cold forging companies tend to replace tool elements when a failure occurs or, anyway, when the product quality is not satisfied any longer (*tool-failure replacement*). This maintenance policy brings to two main consequences:

- tool elements are fully exploited. The first contribution to the maintenance costs (Tool Costs) is minimised, and
- machine stops become frequent. Maintenance operations are caused by one single tool element and the high frequency of maintenance occurrences brings to an increase of downtime costs.

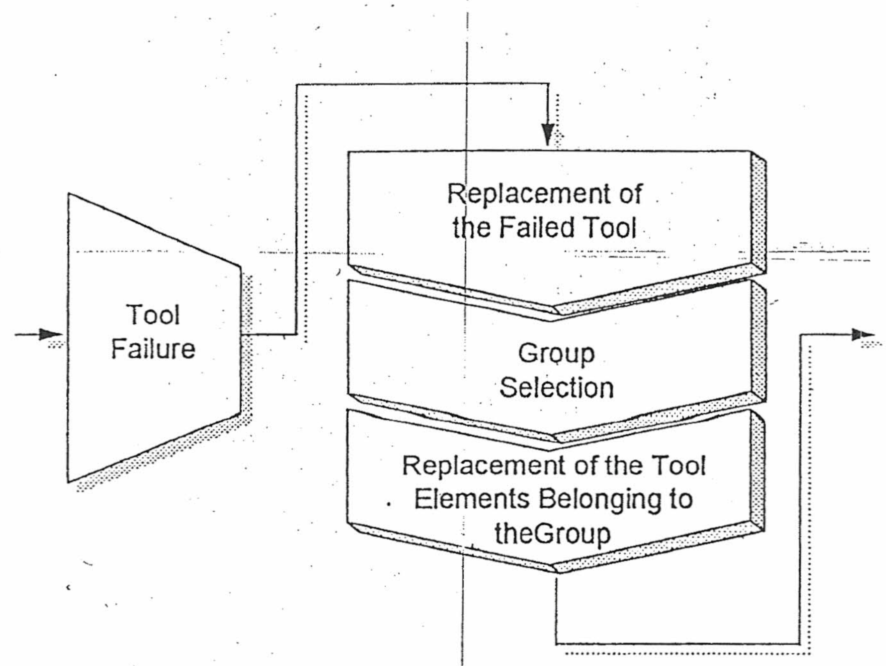


Fig. 2: Tool replacement scheme for preventive maintenance policies.

The main idea underlying a preventive maintenance policy is that of extending maintenance operations to more than one single tool at each press stop, according to some criteria. The time for assembly/disassembly the tool block is divided among all the tools involved in the replacement and, thus, downtime costs are reduced.

The logical structure of a preventive maintenance policy is illustrated in Fig. 2. Tool elements are divided into different groups. On this basis, as a tool fails, the maintenance action provided to the press will be extended to all the elements belonging to the same group.

3. Modelling the Forging System

3.1. The Industrial and Technological Context

A computer assisted procedure has been developed aimed at evaluating the performances of a forging shop floor in terms of maintenance costs. The main objective is that of supporting the user in analysing and comparing different tool maintenance policies in order to design and implement the most favourable program for the maintenance of the forging machines and their relevant tooling systems.

The study has been carried out in the frame of a collaborative research work with the Steel Components Division of Teksid S.p.A., the company representing the Fiat Group's Metalworking sector. Cold forging plants of Teksid are equipped with high production-rate transfer presses (Fig. 3), suitable for producing high-volumes of components, mostly for the automotive industry.

For this category of presses the complete tooling system generally consists of 50 to 80 elements that, according to [9] can be distinguished in three main categories:

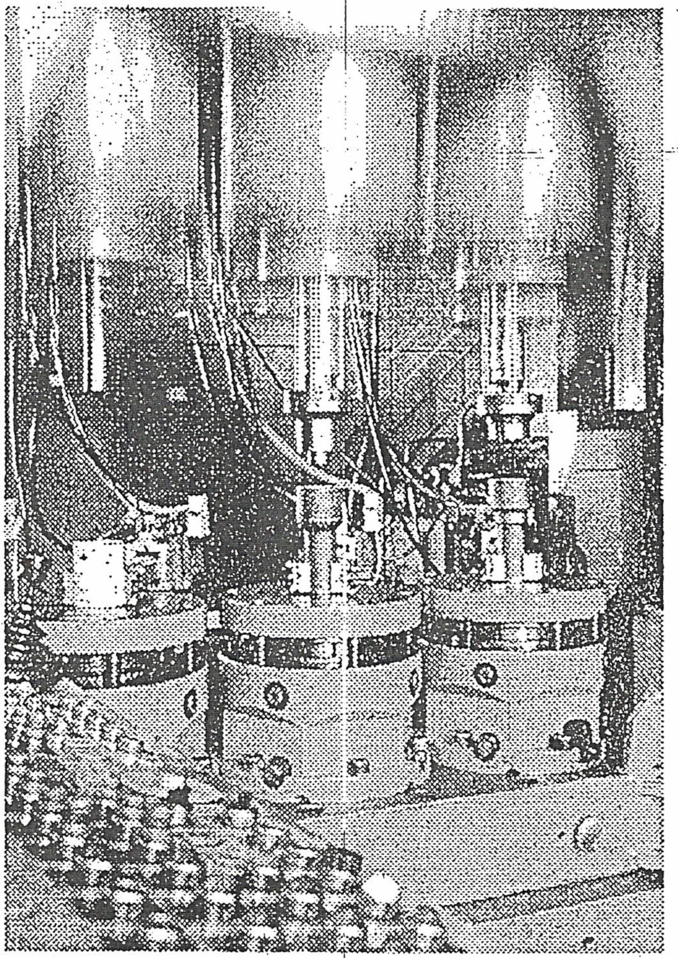


Fig. 3: Hydraulic press for cold forming of rear spindles for industrial vehicles [Courtesy of Teksid S.p.A.].

- *Basic Tooling System Components*, such as housings and pressure pads, involved in several configurations of the tooling system;

- *Tool Configuration Components*, that are additional general components bringing the tooling system to a specific configuration (through -for instance- fixing outer dimensions of punch head and type of ejectors). They are intermediate between the basic tooling system components and the

- *Product-Specific Tool Wear Components*, such as punches, die inserts, and ejectors, that are in direct contact with the workpiece material. These components are interchangeable in the basic tooling system.

In Fig. 4 a list is given of tool components and relevant monitored mean service-life.
They belong to the die set of the first forming station of a 5-station *National 1875* press equipped to process the jackshaft of the scheme of Fig.5. In the figure the tool components are divided according to the above three classes.

Tool Description	Mean Life *(x 1000)*
1. Basic Tooling System Components	
Base-Plate	1000
Housing	980
Housing	1100
Pressure Pad	5000
Pressure Pad	3500
2. Tool Configuration Components	
Stress Ring 1	120
Stress Ring 2	960
Intermediate Stress Ring 1	300
Stress Ring 3	1000
Intermediate Stress Ring 2	350
3. Product-Specific Tool Wear Components	
Punch	25
Die Insert 1	65
Die Insert 2	50
Die Insert 3	50
Ejector	210

Fig. 4: Tool components and relevant mean service life.

3.2. Application of the Discrete-Event Simulation Method

The shop floor performance expected when a specific tool maintenance policy is implemented is measured in terms of total machine downtime and maintenance costs per part (*unit cost*). The relative contributions to maintenance costs from tool replacement, machine downtime and assembly are evaluated together with the importance of each station with reference to maintenance costs.
To this aim a simulation model was developed in SIMSCRIPT II.5 environment, a special purpose language for discrete-event simulation [8].

Discrete-event simulation consists in modelling a system through its evolution over time. The state variables change only at a countable number of points in time called events. The simulation is object-oriented, each object (billets to be forged) entering the model at a well defined simulated time. It becomes active either immediately or at a prescribed "activation time". From this moment, the planned activities are carried out if all the resources required (press, tooling system) are available.

Among the main requirements to be fulfilled, the model has to reflect the stochastic nature of the real manufacturing system where some of the variables are random and spread according to specific statistical functions. The main consequence is that output results may change even thought the input data are always the same.

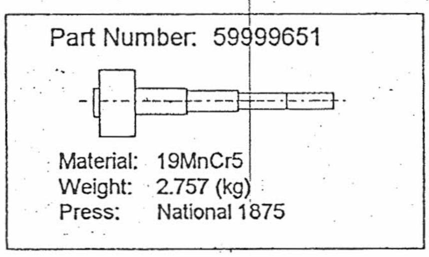
4. Evaluation of Maintenance Policies

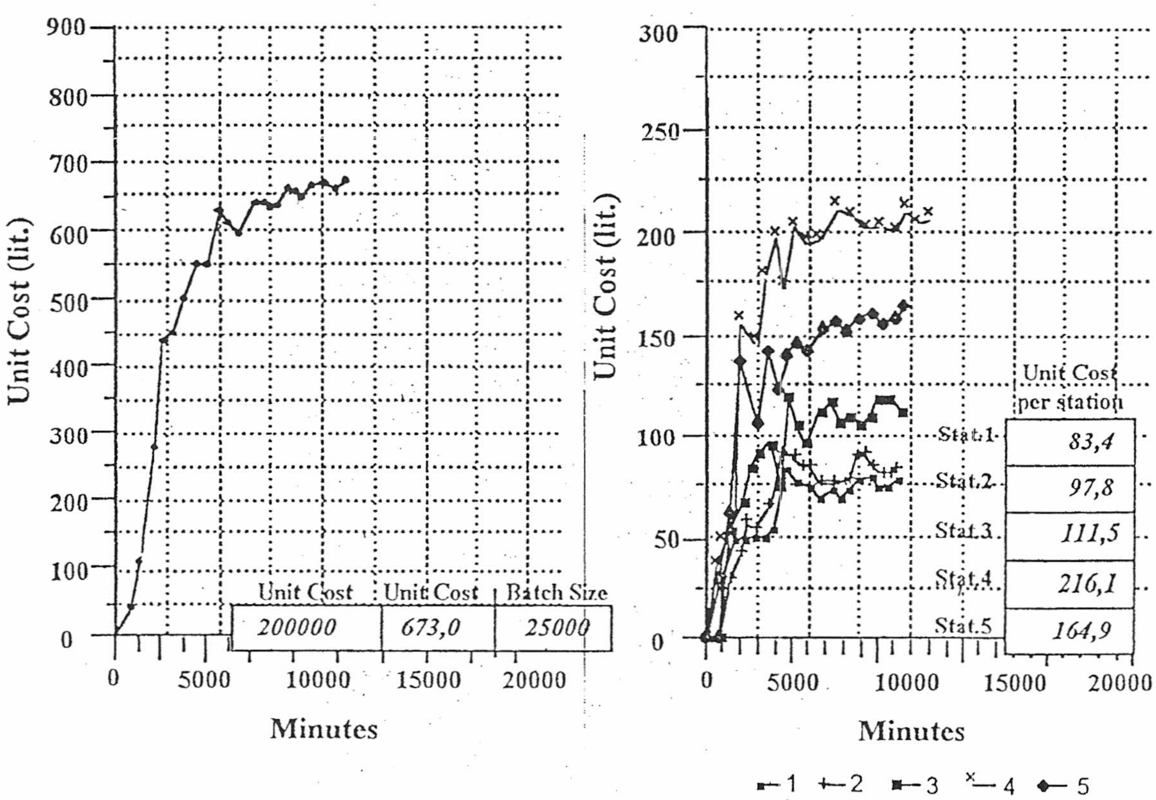
As shown in Fig. 2, different preventive maintenance policies can be generated according to different criteria in grouping the tool components.
With reference to the industrial context presented at § 3.1, the three following preventive maintenance policies were developed and implemented using SIMSCRIPT II.5:

- *family-based policy*, where tool components are grouped according to their expected service lives and technological functions (punch, die, etc.);

- *minimum service life policy*, where a maintenance action frequency is determined as a function of the expected tool service lives;

- *residual expected service policy,* where maintenance action is carried out simultaneously on a set of tool elements according to their residual expected life.





Figs. 5 and 6: Total and per-station maintenance costs vs. elapsed time

In order to evaluate the system performances when the three policies are applied, a considerable amount of data referring to the presses and the tool elements attributes was collected, together with economical details concerning operations carried out on the shop floor. A campaign was launched to record the real service lives for a number of tool elements. The distribution parameters and the constants of the Weibull function were thus identified.

Samples of the program output are given in Figs. 5, 6, 7 and 8. They refer to cold forging of a jackshaft on a 5-station National 1875. The evolution of unit maintenance costs referred to the overall equipment and relevant to each station are illustrated in Fig. 5 and Fig. 6, respectively. Fig. 7 shows the contribution of tool, downtime and assembly costs.

In Fig.8 the shop floor performance when *preventive maintenance* policies are implemented is compared with the corresponding results when a *failure-based* policy is applied. Savings achievable from a preventive maintenance policy are evident. The main justification to these results consists in the relevant reduction of downtime costs provided by this maintenance program.

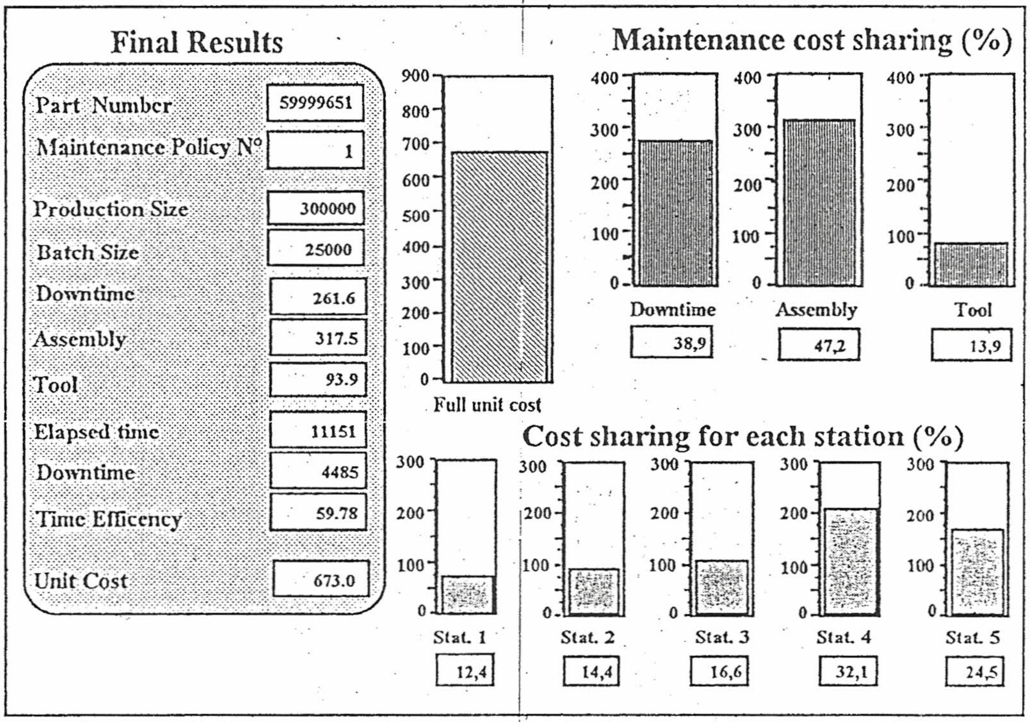
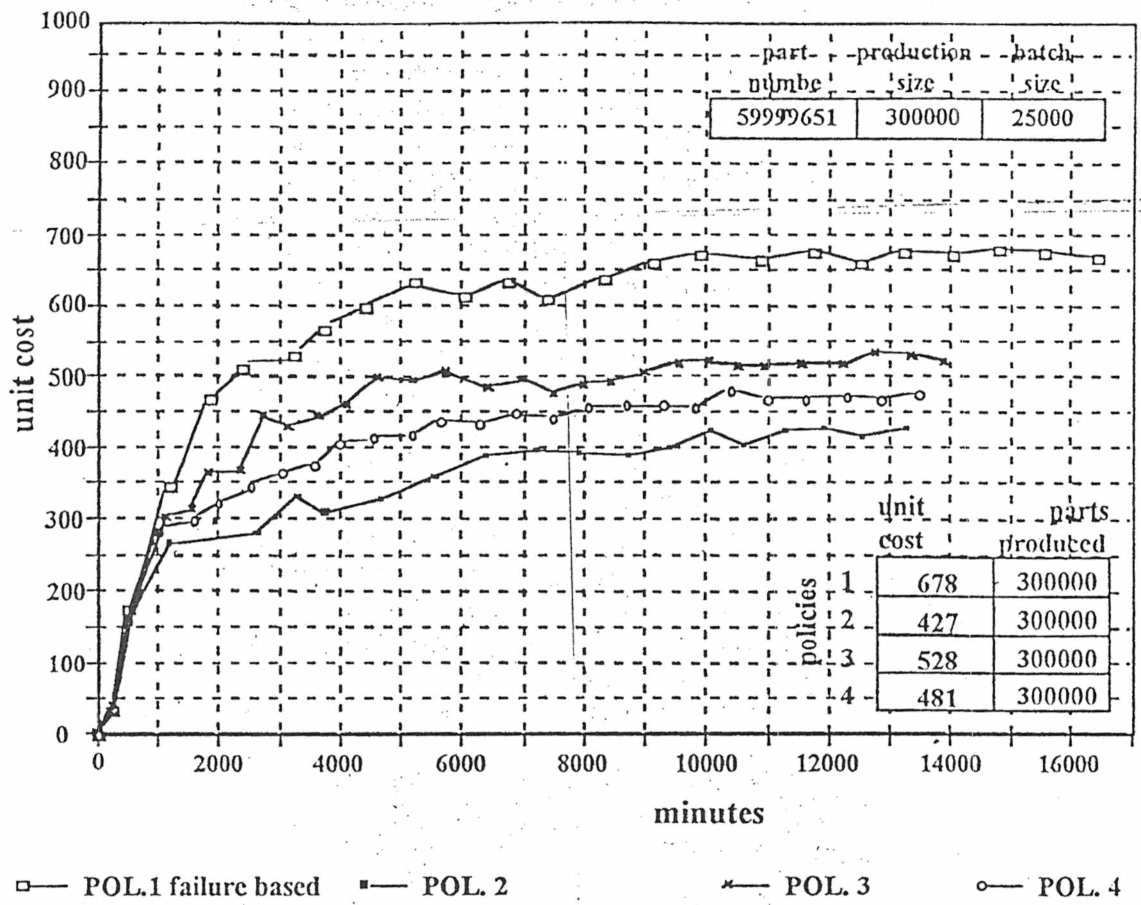


Fig.7: Main contributions to maintenance costs.

The developed procedure is provided with a "*what If*" facility, that can support the user in assessing what happens if the attributes of some "critical tools" (such as tool mean life and scatter, tool cost, assembly times, etc.) are modified. An interesting application of this facility is that of evaluating the economical effects of some surface treatments and coatings of critical tool components.



POL. 1 Failure-Based Policy
POL. 2 Family-Based Policy
POL. 3 Minimum Service Life Policy
POL 4 Residual Expected Service Policy

Fig.8: Maintenance costs vs. elapsed time for different maintenance policies:

To this regard, industrial applications highlighted that tool lives can be steadily enhanced through PVD-TiN coating treatments. Fig. 9 shows that the mean service life of the coated punch is sixfold increased, whilst the scatter is considerably wider than for the uncoated tool component [10].
The increase in life scatter could lead to major problems in scheduling tool changes when preventive maintenance policies are implemented. The effects due to the enhancement of the mean tool life together with the increase of life scatter can be quantitatively determined in terms of press downtime and unit maintenance costs, with a discrete-event simulation. The results highlighted the positive effects of low life scatters when preventive maintenance policies are implemented.

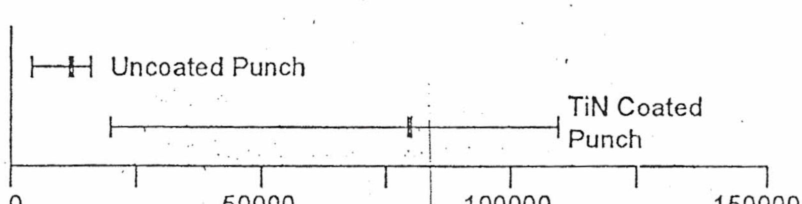


Fig. 9: Range and Mean Tool Life for uncoated and coated punches [10].

- Economical aspects of the service-life distribution for tool components in cold forging technology were discussed.
- Discrete-event simulation procedures are a useful mean for designing and evaluating tool maintenance policies and, thus, supporting decision making in planning tool management.
- The analyses applied to a real cold forging shop highlighted that preventive maintenance policies can lead to reduction of machine downtime and perform a deep exploitation of both equipment and tooling system. However, the most critical aspects in implementing these policies are related to the availability of data concerning the service-life distribution of the tool components and the organisation in the shop floor for their monitoring and collection.

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