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THEORETICAL ASPECTS OF MAINTENANCE PLANNING

by

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Organised in co-operation with the Government of Japan and the Japan Management Association (JMA)

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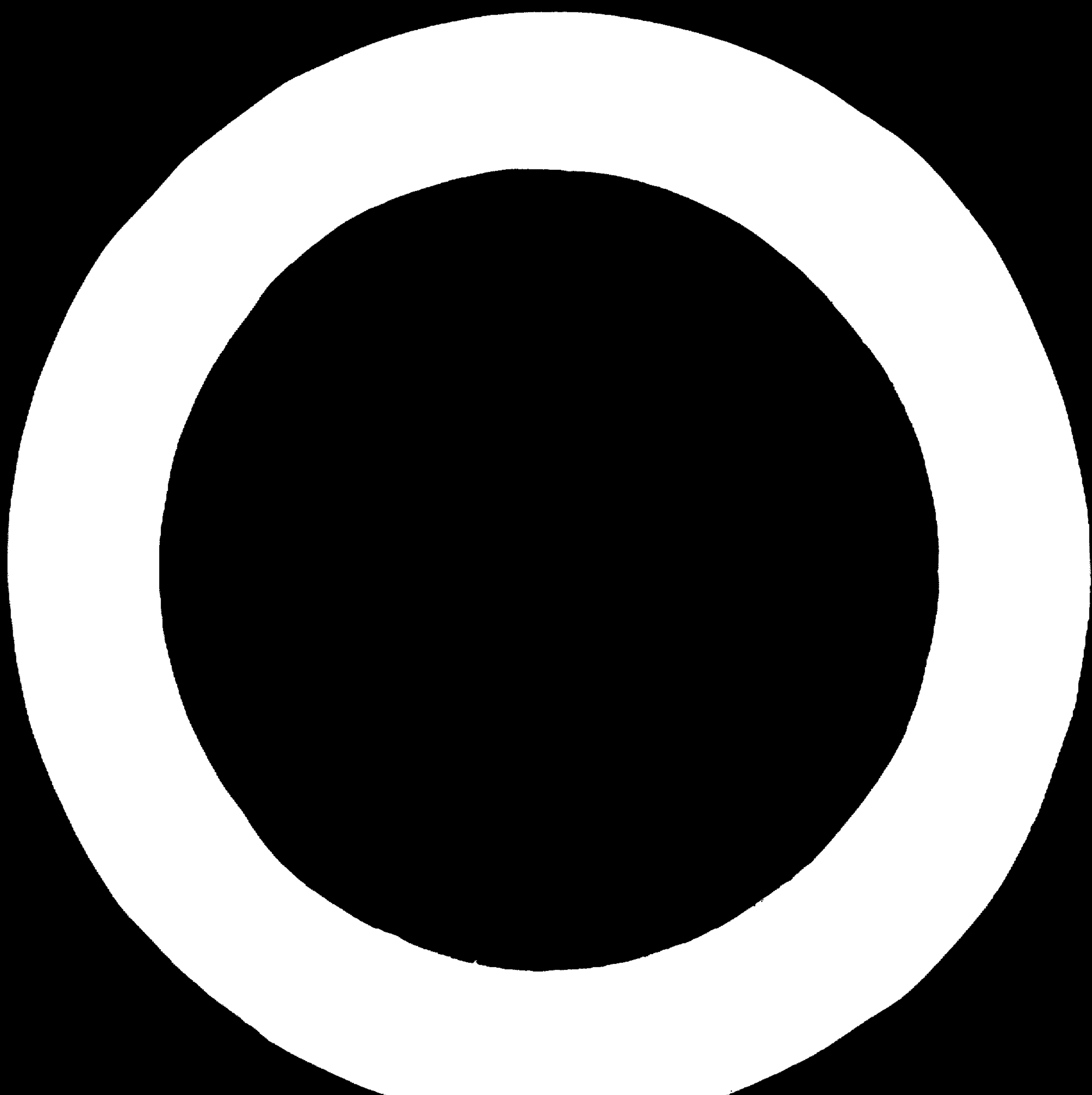


Economy of Maintenance Planning

- Bird's Eye View of Maintenance Theory -

Recently, it has been a trend that production activity depends more and more on the ability of equipment rather that on man's ability. Therefore, it has become of great importance to i) select proper equipment ii) to keep it in good condition in order to demonstrate its ability in full iii) to replace inefficient equipment with the proper one at proper time.

But the subjects of i) selection, iii) removal and renewal of equipment themselves make up one broad area of theoretical study, and which may be considered a little off from the main theme of this symposium. Consequently, let me focus the attention of my presentation to the maintenance of equipment by reviewing the theoretical works achieved so far. It will be my great pleasure if this report can serve as a bird's-eye-view for all the participants here to locate the various studies and practical examples which will be given later on this symposium and to relate one with another.

Classification of Maintenance Theory

Numbers of thesis have been written on the maintenance activity in theory with its emphasis on numerical aspects, but in order to have a total view of these theories, it will be convenient to classify them into two major categories - one involves the theories concerning for production department, the other concerning for maintenance department.

The former can be further broken down into three sub categories : the first concerns determination of timing of repair; the second, the determination of quality level of repair; and the third, the determination of kinds and numbers of spare parts or machines necessary for production.

The latter can be divided into three sub categories as well: the first concerns the theories for determining the kinds and numbers of maintenance equipment, jigs and tools (which include the make or buy problems); the second the theories for examining mechanization of the repair work; and the third the theories for shortening the time length of repair.

This classification is set up for the sake of convenience to understand the general trend of the maintenance theories, thus there are by all means other maintenance theories which are not included into the two major catagories mentioned above. Also, it must be understood that the theories are ever advancing and the subject of study and its scope are ever broadening, therefore it may even be dangerous to make an effort in confining all the maintenance theories to the classification given here. But keeping these things in mind, let us have a view on theories in accordance with the classification given here. The synopsis is listed in the following chart-1.

Chart 1

1. Theories concerning for the production department

   1-1 Theories for determining the timing of repair

   1-2 Theories for determining the quality level of repair

   1-3 Theories for determining the kinds and numbers of spare machines and parts.

2. Theories concerning for the maintenance department

   2-1 Theories for determining the kinds and numbers of maintenance equipments, apparatus and tools.

   2-2 Theories for examining mechanisation of the repair work.

   2-3 Theories for shortening the time length of repair

3. Other theories

1-1 Theories for determining the timing of repair

Among the theoretical research works done on maintenance, this may be the field where the greatest number of research papers have been written. The research made on this category can be classified into following two cases.

1) The case where the operating cost of equipment gradually increases.
(where the function of equipments gradually deteriorates)

2) The case where the equipment stops to function suddenly due to failure.

The reserch made by Dr. Burton V. Dean [1] will be a good reference, where he sums up the work heretofore made in simple and clear form.

In the first case, as the cumulative operating time after the repair increases, the profit gradually decreases, affected by increased operation cost or decreasing in production. Therefore, it is necessary to choose the appropriate time for repair. (Refer to figure-1)

With this type of problem, even if f(x) should represent the random variable, the optimal time for repair can easily be found.

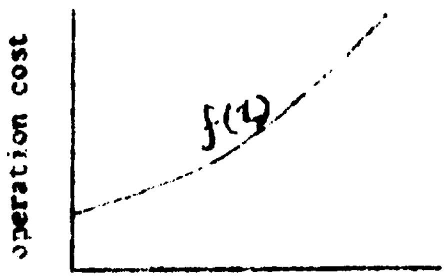


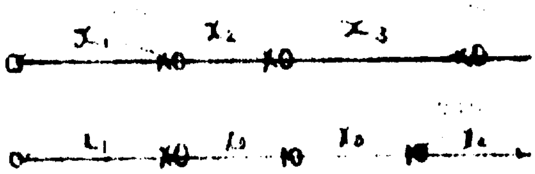
Fig-1 The case where the operation cost gradually increases

In the second case, the simplest example is that the failures of an equipment is brought by parts of one kind. The characteristic of the case is shown in figure-2.

Fig-2 Individually Scheduled Replacement

Replacement after failures

Replacement Before failures



— XO — Replacement of parts after failures

— IO — Replacement of parts before failures

The problem in this case is whether the part should be replaced after the failures, or should be replaced after certain proper time length, say x_0, before the failures. In other words, it will be the problem of individually scheduled replacement before failures.

In the second case, if a failure occurs before the cumulative operating time reaches some predetermined time limit x_0, then the part will be replaced at the time of failure. When a part survives time length of x_0, it is replaced with a new one without waiting for its failure. For this type of problem, please refer to the following graphs from which the optimal time for individually scheduled replacement before failure can easily be found. We will omit the theories on this [2]. In order to use this theory, one must keep the record of time elapsed for each of the parts.

Definition of symbols:

a(yen)= unit price for the part

a_1(yen)=cost for replacing one broken part. (mainly the handling charge, no cost for part)

a_2(yen)=cost required for replacing un-broken part. (mainly handling charge, no cost for the part)

b(yen)= average loss per damage

c.v. = coefficient of variance in life distribution; standard deviation/average life time

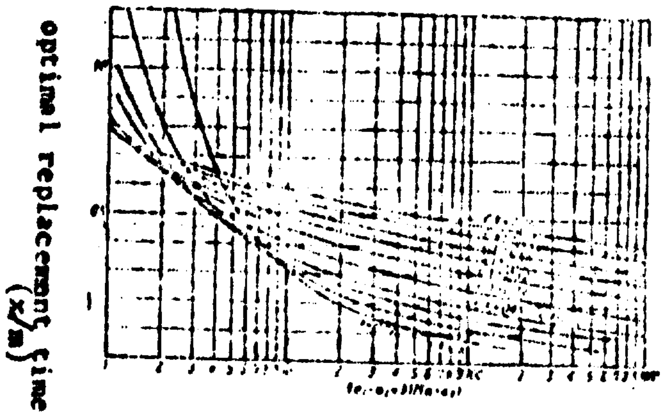


Fig-8 Optimal time for individually Scheduled replacement before failure

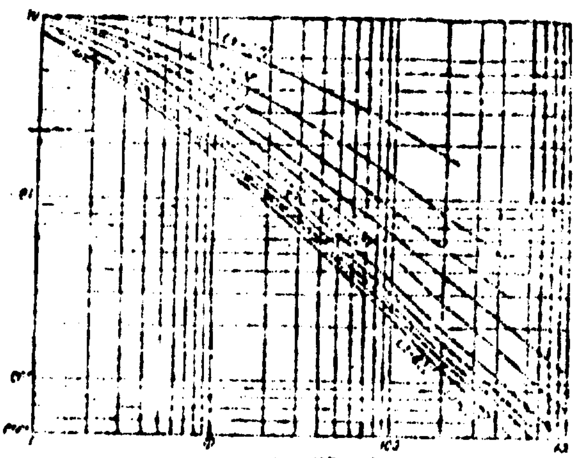


Fig-4 cost ratio of replacement before and after failure

Figure-3 shows the ratio between x_o, the optimal time for individually scheduled replacement before failure, and m , the average life time of the part. In order to find the ratio of x_o to m, first pick the curve which has the coefficient of variance of life distribution, and find the value for $(a_1 - a_2 + b)/(a + a_2)$ on the horizontal axis. For example, when, $(a_1 - a_2 + b)/(a + a_2) = 10$, c.v.=0.32, then $x_o/m = 0.46$. This means the part which has kept itself unbroken till 46% of its life time should be replaced with the new part at that time.

Figure 4 shows the ratio of the cost required for individually scheduled replacement before failures, to the cost required for replacement after failures. Taking the previous example, the cost for replacement before failure will be approximately 23%, which is less than 1/4 of the cost required for replacement after failures.

Figure -5 shows the theoretical average damage rate for the most proper way of performing individually scheduled replacement before failures. In the previous example, it is most appropriate when the average damage rate is 2%. Therefore, if the actual damage rate is significantly greater than that this means the time for replacement is too late, and vice versa. It will be convenient to use the statistical control chart for damage rate together with this graph.

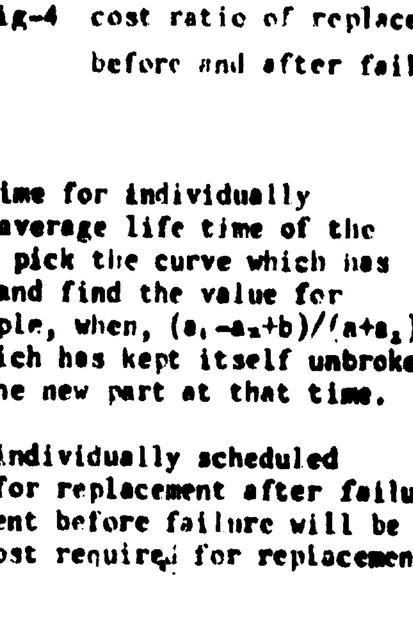


Fig-5 optimal damage rate

When there are numbers of parts of the same kind for one production equipment, it is sometimes advantageous to replace all the parts simultaneously at certain time, say x_0, (Refer to Figure-6)

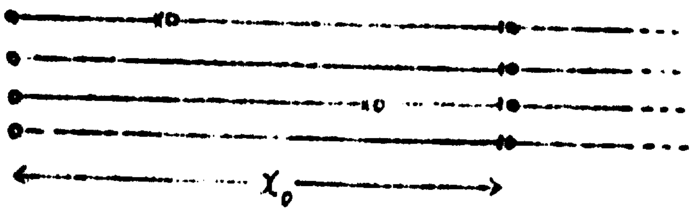


Fig-6 Model for simultaneous replacement before failure

For this type of problem, there are graphs, as in the case of individually scheduled replacement, showing the most proper time for the simultaneous replacement before failure, comparison in cost for the simultaneous replacement before and after failure, and the optimal expected number of damage. The method of using these graphs will be the same as in the graphs previously mentioned.

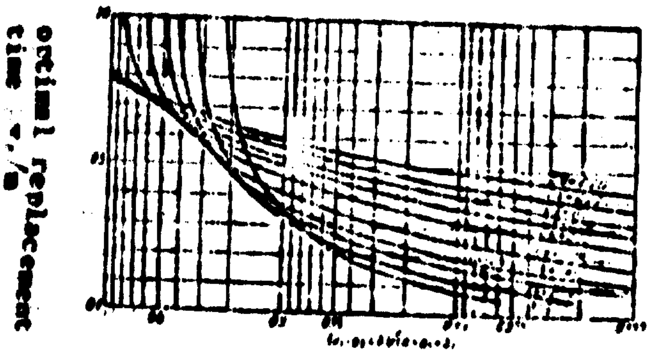


Fig-7 optimal time for simultaneous replacement before failures

Definition of symbols:

a(yen) = unit price for the part

a_1(yen)= cost for replacing one broken part. (mainly the handling charge, no cost for part)

a_2(yen)= cost required for replacing un-broken part. (mainly handling charge, no cost for the part)

b (yen)= average loss per damage

c.v. = coefficient of variance in life distribution; standard deviation/average life

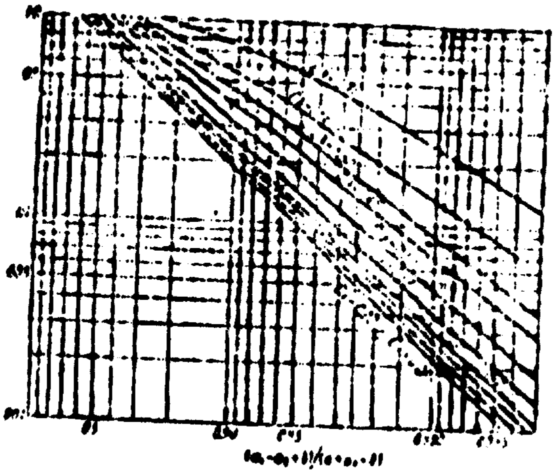


Fig-8 ratio of cost in replacement before and after failure

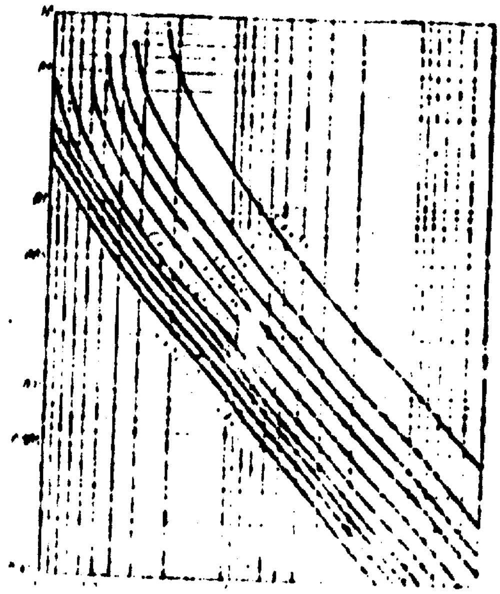


Fig-9 optimal expected number of failure

The purpose for introducing the theories of these two cases is to make clear the important role the probability theory plays in rationalising the preventive maintenance. Of course in practice, production equipment is constructed by many parts of different kinds and the actual maintenance involves the combination of check-up, minor repair, and major repair, therefore the case is not so simple as has been mentioned earlier. In order to solve these problems, it is quite natural that we need the higher level of theories, for which the some theoretical study has already been published. Some of these may be difficult to put into practice as they are, but among the comparatively new references,[3] through[9] which have been written in English may be recommended to get an idea.

1-2 Theories for determining the quality level of repair

The problems that the industrial corporations frequently encounter are those of determining the recovery level of the function of production equipment after the repair has been made. Certainly, there is no problem if the function of equipment recovers to the highest level without costing much. But in general, it costs much to bring the function up to the high level of recovery.

Quality level of repair includes the following two kinds of problems. The first concerns the recovery level of function. The problem here is to determine as to what level the function of the equipment should be recovered by having it repaired. And in the case where the defective rate of the product is affected by the process capability or processing precision of the equipments, the problem of determining the recovery level directly affects company's profit. In case of maintaining the boilers, low recovery level will give a bad effect on heat efficiency. In general, the higher the recovery level, the better the operating efficiencey, by all means. But, in many cases, if the level becomes higher than a certain limit, it will bring up the cost in great amount. There should be a proper level of recovery. This is the first problem concerning with the quality level of repair.

The second problem concerns the cause factor which affects the intervals of repair. For example, by using a high quality packing for a certain equipment, the intervals between the repairs could be extended, keeping the level of recovery the same. Another example is, in painting building of the factory, using good quality paint will lengthen intervals between the paintings hereby reducing the total cost of labor and the paint.

Therefore, when the labor cost amounts high, use of good quality paint is economical.

There is, of course, the case that these two problems are closely inter-related. Taking the water pollution problem for instance, it is sometimes true that high level of recovery lenghtens the repair intervals, since the law specifies the allowable maximum percentage.

In examining the problems like these, the theories stated earlier in 1-1 may be applicable, but in many cases, the existing theories developed in other fields are applied. Mathematical statistics is used in analyzing the relationship between process capability and defective rate, and Engineering Economy [10] for investment calculation. Although these theories are useful, we will not go into further details here, because these are not called traditional maintainance theories.

1-3 Tactics for determining the kinds and numbers of spare machines and spare parts

If there are spare machines which can replace machines when broken, it may be possible to avoid the reduction of production volume, so as to prevent the reduction of sales profit and delay in delivery, but so doing needs the investments for spare machines and space for them.

For the equipment whose failures heavly affect the whole operation of the factory such as generators of electric power, boilers and compressors, the spare equipment is usually stored , for the reason stated above. But failure is not so major and it does not greatly affect the whole operation of the factory, it is in most cases more economical to have a spare for a certain small part of equipment or for special parts. And this brings up the problem of determining how many of what spare parts should be stored. The necessary number of spare parts depends on its lead time. But having more of the expensive parts causes the higher cost.

Therefore, in order to enforce the economical control of spare parts, it needs to determine the time and amount of spare parts to be purchased. Concerning this type of problem, the theory called "inventory control" in the field of Operations Reserch will be of valuable use. But, in applying the theory, it is necessary to standardize the parts or to devise the plant layout so as to carry the repair work quickly. Otherwise the theories may not give good effect as it should.

When large amount of capital investments are involved, engineering economy will be useful in order to determine whether the spare equipment should be used or rather small spare parts should be used for substitute. Having or not having the spare equipment and spare parts will make a big difference in damage cost at time of failure, and this, in turn will affect the interval of preventive maintenance. So, these must always be taken into consideration to examine the maintenance problems.

2-1 Theories for determining the kinds and numbers of maintenance equipments, apparatus and tools.

When the scale of maintenance capacity is large, the whole repair work may be completed promptly even when a great number of machines must be repaired simultaneouly. If such is a case, downtime loss of the equipment may be little and few spare parts will be needed. But on the other hand, a large amount of investments for equipments will be required for large maintenance capacity.

But, in another case, if the maintenance equipment is of small scale, there are opposite shortcomings. Therefore it is significant to determine the suitable scale for maintenance capacity. The same will be true for apparatus, machines, jigs, and tools.

The theory which is most frequently applied to this type of problem may be the Queueing Theory. When the machines break down and they can not be repaired immediately, there will the machines waiting in a line. The theory examines how the number of machines in line varies with such factors like the scale of maintenance capacity, the size of repair crew, the probability of failures and so on, by using probability theory. In this problem, break down intervals of equipment and the net repair time are regarded as random variables, and if the probability functions of these random variables have the specific probability densities, the problem can be solved by using the probability theory. Using this theory, it becomes easy to examine this type of problem from the economic point of view. But in practice, [illegible] problem of maintenance is more complicated.

In many cases, machines which require repair are found after the regular inspection and the number of machines sent to repair department does not necessarily belong to the same population every day. Among those machines sent to the repair factory, some may need immediate repair and some may not. Also, we can not neglect that even if they are sent to the factory, the maintenance equipment of the factory may not operate due to failures. Therefore, in investigating the actual repair work theoretically, Queueing Theory may be applied less than expected, as the way the theory is.

For the reasons stated above, simulation technique is more practical than the probability theory. It is not impossible to perform simulation manually but in most cases, it is done by using computers these days.

2-2 Theories for mechnization of repair work

Mechanization of repair work, as well as the mechanization of production work, is one of the important methods for reduction of the cost. But the effectiveness of mechanization is closely connected with labor cost and investments for equipment. Therefore the same effect of the automatic lubricating equipment in a country with higher labor cost can not be expected in a country with lower labor cost. But the underlying theory will be common to both, except for the value of input data such as cost factor.

For this type of problem the theories of Engineering Economy will be useful. Possibility of mechanization will be determined by comparing the factors like initial investments necessary for mechanization and routine operating cost with possible reduction of labor cost. This theory can also be applied to the case where there are several alternative proposals for mechanizing maintenance work such as the use of expensive machines or less expensive machines.

Suppose, three alternative investment proposals are given, say A_1, A_2, and A_3, for automatic lubricating equipment, and two alternatives, say B_1, B_2 for apparatus for measuring wear out rate and three alternatives, say C_1, C_2, and C_3 for automatic assembler for the use in maintenance department. And suppose that the budget given to maintenance department is not enough. Under these circumstances, one must make a selection so that the effect of the mechanization will be maximum within the limit of given budget. If the plans are many in numbers it will be a rather complicated investment problem, but there exists simple systematic method of solving for it. [11]

In maintenance department, there is a similar but more complicated problem.

But, most important mission of the maintenance department is not try to adjust the investments and costs, but to manifest the ability of production equipment in full. In comparison to this, the cost reduction within the maintenance department is not so important. Nevertheless, the demands of maintenance department may not be totally accepted because of limitation of financial or human resources. Therefore it is necessary to know clearly what is involved in the making of most favorable investment plan for the maintenance department. Under the various limitations of various resources (such as capital and personnel requirements), select the proper means among the group of several alternative proposals mentioned earlier, and further if possible, materialize the reduction of cost in the maintenance department.

When the problem becomes complicated as in this case, higher level of Operations Research technique such as integer planning [12] or linear programming [13] will be necessary. But considering the complexities of the practical problems, it should be evaluated high in practice, even it does not give the optimal solution in a Mathematical sense. At this view point, Effective Gradient Method 14 and its variations may be regarded as effective theories.

2-3 Theories for shortening the time length of repair

When a factory has a great production capacity as compared with the required production volume because of shortage of demand or raw materials, as is often seen in times of business depression, damage loss is not so much. However, in general, it is a common practice that, if a large size production equipment breaks, the damage loss amounts to be enormous.

Therefore, it will be desirable for most industries to do the construction, replacement of the equipment in a short time. For this it will be important to make an elaborate plan on the procedures, as well as the preparation. The Gantt chart which has been used primarily in the industrial engineering field is in frequent use for this, but it is not sufficient to examine the interrelationship among the various improvement activities. The most suitable method is PERT (Program Evaluation and Review Technique) or CPM (Critical Path Method). In dealing with a large scale facility the use of computer may be necessary.

If the scale of facility, the number of repair crew and the number of repair tools increases in the maintenance department, it will become easier to complete the repair in a short time. And this will reduce the downtime loss which in turn makes it possible to lengthen the intervals of overhaul and to reduce the number of spare machines. In this way, all the factors are closely related to one another.

3. Other theories and their relationships

Since the works performed in the maintenance department is of great variety, many existing theories may be applied in variety of cases. Methods engineering and work measurement which have been developed in the field of industrial engineering are by all means applicable to almost all the repair work that the maintenence department is responsible for. But since the job is of wide variety rather rough techniques of measurements such as work-sampling technique or Multi-Regression Analysis are more suitable than precise time estimation method using micromotion films, stop watches and so on. Also, those theories concerning material handling, plant layout and scheduling are also important tools for maintenance department. Techniques on cost control and budget control can not be left out either.

In the maintenance department there are many problems concerning many different fields, and theories which may be applicable are of great variety. To give examples of these problems, there are problems on organization and administration of the maintenance department within the corporation, method of training, make or buy problems, maintenance prevention by the feedback to either planning department or to purchasing department, and individual technical problems on maintenance.

Therefore it is almost impossible to show the total view of maintenance work by presenting all the theories and establish their distinctive interrelationships. Even rough and incomplete it may be, showing bird's-eye-view of activities of maintenance department may be of significance. The effort is shown on chart 10.

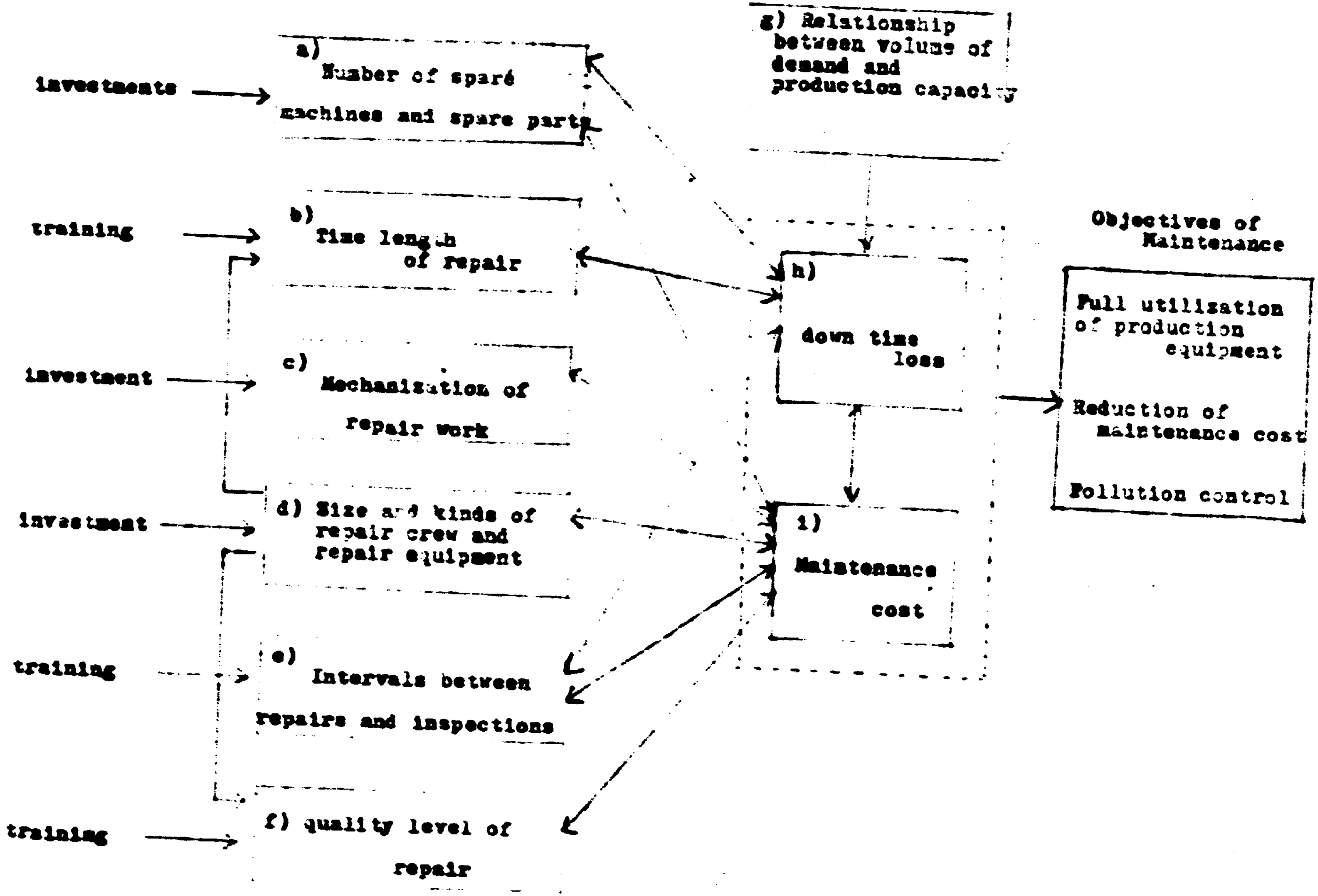


Fig-10 Relationship of improvement activities in Maintenance

Let us consider a simple example here. Although there exists theories using probability for determining the economical interval of repair and inspection, first, it is important to examine closely the necessity of preventive maintenance by finding how much the down time loss will be, which are affected by the relative volume of demand and production capacity. Even if the production can not meet the demand, a) down time loss can be reduced by having spare machines or spare parts, or d) by increasing repair equipment or if b) repair time can be shortened, then h) down time loss will be reduced and e) the interval of preventive maintenance can be made longer, and there may even be the case that preventive maintenance may not be needed.

The essential for the maintenance department is to set up the policy considering over all economy with a broad view not in a manner to hasten the conclusion in a small area. To do this, once the main objective is set, one must make a good use of all the theories, in such a way to fit the right theory in a right place. In a sense, it is like an art. There is no end in maintenance, the future is wide open. Effective theories are to be developed to make a proper plan systematically for the maintenance, the field which is so complicated and intricate. It is no doubt that they will emerge through shared efforts and cooperation on the part of enlighted people of all over the world.

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