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A Methodology for Quality Goal-seeking and Coordination, and the Practical Application

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Abstract—Japan has achieved a high level of the practice of quality control in industries. Characteristic to it is that it has successfully taken the form of company-wide quality control activities. In order to coordinate diverse activities at a company, 'quality-evolution', which is essentially a process of refinement of means-end relationship, plays an important role. This paper discusses the basic recognition underlying the practice of quality-evolution and presents on a conceptual level a general theory and methodology of goal expansion which is usefully applicable to any goal-seeking activities under situations where the relevance of diverse activities to goals is not necessarily clear and schemes for goal-oriented coordination of the activities are required. Such situations also often occur when better performance of systems are newly required.

INTRODUCTION

JAPAN has achieved a high standard of the practice of quality control in industries. Characteristic to the practice of quality control in Japan is that it has successfully taken the form of 'total quality control (TQC)' of Feigenbaum [1], or the form of company-wide quality control. Many factors, ranging from organizational climate to purely scientific and technological aspects, have contributed to the coordinated activities of company-wide quality control in Japan. From the viewpoint of industrial engineering, it is safely said that one of the major factors of the success is a wide use of charts and tables with various names such as 'Required Quality Expansion Table', 'Quality Control Process Overview', 'Quality Assurance Chart' [6].

These have been devised at various companies under the guidance of TQC consultants as tools to coordinate company-wide quality control activities, and so they take a variety of forms. However, the basic recognition underlying them is simple and it can be summarized as follows:

(1) The quality of final products is determined by the overall activities through the stages of planning, designing and manufacturing.
(2) In order to achieve a given quality goal effectively, a 'clear picture' showing how the effects of the activities are related in reference to the quality goal is required.
(3) In a large and complex system such as a company, a clear picture for the activities involved in the 'quality forming or realizing process' is only obtained through an expansion or an 'evolution' of the given goal.

Because of the feature (3), the name 'quality-evolution' has been given to the preparation of such tables or charts and, loosely, also to the overall coordinating activities using them. One of the present authors has been participating in the development of the idea and practice of quality-evolution in Japan from its earliest stage, and his feeling is that these common features, especially (1), have not always been fully recognized and unsuccessful quality-evolutions have not been unusual. A typical quality-evolution is conducted as follows: given quality goals are 'expanded' in terms of quality characteristics and required levels of the quality characteristics are specified together with the activities which are assumed to be responsible for the realization of the levels. This type of expansion is conducted down through finished products, various components' individual parts to raw materials. Because it involves many activities of different kinds and levels, e.g. from mere inspections to managerial decisions, quality-evolution itself becomes complicated and it is often forgotten that the key activities are those directly concerned with engineering techniques. Thus a simple and penetrating framework is needed for efficient quality-evolution.

In this paper, in order to give explicit consideration to engineering techniques, we will introduce the concepts of quality-system, QE-domination, QE-evolution and quality-simulation. Quality-system is an input–output system whose inputs are engineering techniques and whose outputs are qualities. It serves as a framework in which the concepts of QE-domination, QE-evolution and quality-simulation are developed. QE-domination expresses a cause–effect relationship between engineering techniques and quality characteristics, whereas QE-evolution corresponds to a means–end expansion, or a process of refinement of means–end relationship between engineering techniques and quality characteristics. Quality-simulation, based on these concepts, is introduced as a way to predict the transition of qualities through stages under engineering techniques applied. Furthermore, we will show a system and a tool to practice these ideas effectively for quality goal-seeking.

In introducing these concepts, we employ a set theoretical formalism of the mathematical general systems theory [5]. We are well aware of the fact that such complicated activities as are involved in a company-wide quality control cannot be fully described with such a rather simple framework. But our opinion is that just because they are complex and complicated, some simple but penetrating attitude toward them is required in order to capture essential aspects of them and coordinate them efficiently. As is easily seen, what we develop theoretically in this paper is not restricted to the field of quality control. But in order to retain original concerns, we shall keep our presentation quality control oriented. We also present a practical application of our theory, or attitude, although in a simplified form.

QUALITY-SYSTEM [3]

We shall introduce here the concept of quality-system in order to develop an idea or a way for quality goal-seeking. A quality-system is a conceptual system of a process where product quality is formed or realized (we shall call the process the 'quality forming process') and will be defined as follows. The definition is based on the recognition that an engineering technique essentially works as a cause and there exists a quality as an effect thereof.

Definition 1: *Quality-system*

A quality-system is an input–output system:

$$S \subset \prod_{a \in A} E_a x \prod_{b \in B} Q_b$$

which expresses the input–output relationship between techniques available and quality obtainable thereby during a quality forming process, where A is a set of technical factors in a quality forming process; B is a set of quality characteristics in a quality forming process; E_a is a set of techniques available for $a \in A$; Q_b is a set of quality characteristic values taken by $b \in B$; Π and x are Cartesian products.

Hereunder, the Cartesian product $\Pi_{y \in Y} x_y$ will be abridged $\Pi_{y \in Y} x_y$. The definitions of notations employed for a quality-system are as follows: Gc is a quality goal, which is assumed to be given by specifying a set of satisfactory qualities, $Gc \subset \Pi_C Q_b$, for an appropriate subset C (a set of target quality characteristics) of B: $(e)_I$ and $(q)_J$ are respectively the restrictions of e to I and q to J:

$$E = \{e \mid (\exists q)((e, q) \in S)\}:$$

$$E_I = \left\{e_I \in \prod_I E_a \mid (\exists e' \in E)(e_I = (e')_I)\right\}:$$

$$Q = \{q \mid (\exists e)((e, q) \in S)\}:$$

$$Q_J = \left\{q_J \in \prod_J Q_b \mid (\exists q' \in Q)(q_J = (q')_J)\right\}:$$

$$S(e) = \{q \mid (e, q) \in S\}:$$

$$S(e)_J = \left\{q_J \in \prod_J Q_b \mid (\exists q' \in S(e))(q_J = (q')_J)\right\}:$$

$$Se_I = \{(e', q) \in S \mid e_I = (e')_I\}:$$

$$E(e_I) = \{e' \in E \mid e_I = (e')_I\}:$$

$$Se_I(e')_J = \left\{q_J \in \prod_J Q_b \mid (\exists q')((e', q') \in Se_I \text{ and } q_J = (q')_J)\right\}$$

$$(Se_I)_J = \cap \{Se_I(e')_J \mid e' \in E(e_I)\},$$

where I and J are respectively arbitrary subsets of A and B: e, e_I and e' are respectively arbitrary elements of $\Pi_A E_a$, E_I and $E(e_I)$.

In this paper, $E = \Pi_A E_a$ is supposed for a quality-system. The assumption means that individual engineering techniques are available each independently.

QE-DOMINATION AND QE-EVOLUTION [3]

The definition of a quality-system is macroscopic and simple, but a quality-system may be structurally complicated. In fact, one can often perceive the existence of more detailed causal relationships between engineering techniques and quality characteristics and also among quality characteristics themselves. If any, we are interested in the causal relationships on the basis of such attribute domination as the following.

Definition 2: *QE-domination*

In a quality-system

$$S \subset \prod_A E_a x \prod_B Q_b,$$

let J and ΔJ be arbitrary subsets of B and ΔI an arbitrary subset of A. $(\Delta J, \Delta I)$ QE-dominates J in S iff

$$(\forall(e,q), \forall(e',q') \in S)((q)_{\Delta J} = (q')_{\Delta J}$$

and

$$(e)_{\Delta I} = (e')_{\Delta I} \rightarrow (q)_J = (q')_J)$$

holds.

The meaning of the above condition is that a quality of J is completely determined by the combination of a quality of ΔJ and an engineering technique employed for ΔI. This implies that any engineering techniques $e_{\Delta I}$ and any quality $q_{\Delta J}$ participate in forming a quality of J.

We can now introduce the idea of QE-evolution which is concerned with a means–end expansion.

Definition 3: *QE-evolution*

In a quality-system

$$S \subset \prod_A E_a x \prod_B Q_b, \text{ let } Gc \subset \prod_C Q_b$$

be a quality goal. For each natural number n, set

$$EVO^n(Gc) = \{((\Delta J^k, \Delta I^k), \Delta J^{k-1}) \mid k \in Nn\}$$

is defined which satisfies the following conditions:

(a) $\Delta J^0 = C$
(b) $(\forall k \in Nn)(((\Delta J^k, \Delta I^k), \Delta J^{k-1}) \in QED(S))$
(c) $(\forall k, \forall m \in In)(k \neq m \rightarrow \Delta J^k \cap \Delta J^m = \phi)$
(d) $(\forall k, \forall m \in Nn)(k \neq m \rightarrow \Delta I^k \cap \Delta I^m = \phi)$

where $QED(S) = \{((\Delta J, \Delta I), J) \mid (\Delta J, \Delta I)$ QE-dominates J in $S\}$; Nn and In are respectively sets of natural numbers and non-negative integers less than or equal to n; ϕ is empty set. Here, the operation of step by step obtaining $EVO^1(Gc)$, $EVO^2(Gc), \ldots, EVO^n(Gc)$ is referred to as the nth QE-evolution with respect to Gc.

From a practical viewpoint, in the above definition each superscript corresponds to a stage through which product quality is formed. On the other hand, as is easily seen, ΔJ^{k-1} and $(\Delta J^k, \Delta I^k)$ respectively play roles as a temporary target and a means in obtaining $EVO^k(Gc)$. After that ΔJ^k becomes a new temporary target. In that sense, QE-evolution corresponds to a process to systematically refine a means–end relationship between engineering techniques and quality characteristics.

In the process ΔJ^k and ΔI^k are causally rela to ΔJ^{k-1}. But, except for ΔJ^1 and ΔI^1, the definition does not clearly express whether or nor they have causal relation with C, in other words, they participate in realizing the given quality goal. For this problem we have the following proposition. For the sake of convenience, on what follows $EVO^n(Gc)$ itself shall be referred to as the nth QE-evolution with respect to Gc.

Proposition 1

In a quality-system

$$S \subset \prod_A E_a x \prod_B Q_b, \text{ let } Gc \subset \prod_C Q_b$$

be a quality goal. For the nth QE-evolution

$$EVO^n(Gc) = \{((\Delta J^k, \Delta I^k), \Delta J^{k-1}) \mid k \in Nn\}$$

with respect to Gc, let

$$I^n = \bigcup_{k=1}^{n} \Delta I^k.$$

Then $(\Delta J^n, I^n)$ QE-dominates C.

Proof: see the bibliographic item 3. The above proposition also implies that each temporary target in $EVO^n(Gc)$ can be regarded as a 'state' in the process of QE-evolution.

Thus, it is safely said that QE-evolution plays an important role as a way to accomplish the following:

(1) To obtain systematically a clear picture showing a cause–effect relationship or a means–end relationship between engineering techniques and quality characteristics with respect to a given quality goal.
(2) To clarify systematically engineering techniques which participate in realizing the goal.

From the view point of quality goal-seeking it is an important problem to investigate which engineering techniques can achieve a given quality goal. The above (1) and (2) are requisite for the solution of the problem. In that case, it is required to make clarification of all engineering techniques to participate in realizing the goal. However, a usual QE-evolution does not necessarily perform it. The following proposition will show what type of QE-evolution ought to be executed for it.

Proposition 2

In a quality-system

$$S \subset \prod_A E_a x \prod_B Q_b, \text{ let } Gc \subset \prod_C Q_b$$

be a quality goal. For the nth QE-evolution

$$EVO^n(Gc) = \{((\Delta J^k, \Delta I^k), \Delta J^{k-1}) \mid k \in Nn\}$$

with respect to Gc, let

$$I^n = \bigcup_{k=1}^{n} \Delta I^k.$$

If ΔJ^n in $EVO^n(Gc)$ satisfies condition 1:

$$(\forall e \in E)(S(e)_{\Delta J^n} = Q_{\Delta J^n}),$$

then

$$(\forall e, \forall e' \in E)((e)_{I^n} = (e')_{I^n} \rightarrow S(e)_C = S(e')_C)$$

holds.

Proof: see the bibliographic item 3. Proposition 2 implies that through QE-evolution to meet Condition 1, the engineering techniques to participate in realizing the given quality goal can be clarified without omission. In that sense, such QE-evolution shall be especially referred to as 'complete QE-evolution', and it will be defined as follows.

Definition 4: Complete QE-evolution
In a quality-system

$$S \subset \prod_A E_a x \prod_B Q_b, \text{ let } Gc \subset \prod_C Q_b$$

be a quality goal and

$$EVO^n(Gc) = \{((\Delta J^k, \Delta I^k), \Delta J^{k-1}) \mid k \in Nn\}$$

the nth QE-evolution with respect to Gc. If ΔJ^n in $EVO^n(Gc)$ satisfies Condition 1, then it is called the nth complete QE-evolution with respect to Gc.

It is obvious that complete QE-evolution is essential to the solution of the above mentioned problem.

QUALITY-SIMULATION [4]

In this section, the idea of quality-simulation is introduced and discussed as a way to predict the quality transition during stages under techniques applied and to investigate engineering techniques to realize a given quality goal.

First, we introduce the concept of technomodel as a basic model to predict such quality transition.

Definition 5: Technomodel
In a quality-system

$$S \subset \prod_A E_a x \prod_B Q_b,$$

let ΔI be an arbitrary subset of A; J and ΔJ arbitrary subsets of B; $e_{\Delta I}$ an arbitrary element of $E_{\Delta I}$. $\Phi^J_{\Delta J}(e_{\Delta I}) \subset Q_{\Delta J} x Q_J$ are defined as follows:

$$(q_{\Delta J}, q'_J) \in \Phi^J_{\Delta J}(e_{\Delta I}) \overset{\text{def.}}{\leftrightarrow} (\exists (e', q') \in S)$$

$$(e_{\Delta I} = (e')_{\Delta I} \text{ and } q_{\Delta J} = (q')_{\Delta J} \text{ and } q'_J = (q')_J),$$

where $q_{\Delta J}$ and q'_J are respectively arbitrary elements of $Q_{\Delta J}$ and Q_J. Here, if $\Phi^J_{\Delta J}(e_{\Delta I})$ is a function of $Q_{\Delta J}$ to Q_J, then it is called an $e_{\Delta I}$-based technomodel related to ΔJ and J.

The sentence 'if . . . function' in the above definition implies that a technomodel does not necessarily exist. Some conditions for the existence can be obtained, but we show only the following proposition because it gives the condition directly concerned with quality goal-seeking.

Proposition 3
In a quality-system

$$S \subset \prod_A E_a x \prod_B Q_b, \text{ let } Gc \subset \prod_C Q_b$$

be a quality goal and

$$EVO^n(Gc) = \{((\Delta J^k, \Delta I^k), \Delta J^{k-1}) \mid k \in Nn\}$$

the nth complete QE-evolution with respect to Gc. Then, for any $k \in Nn$ and $e_{\Delta I^k} \in E_{\Delta I^k}$, $\Phi^{\Delta J^{k-1}}_{\Delta J}(e_{\Delta I^k})$ is an $e_{\Delta I^k}$-based technomodel related to ΔJ^k and ΔJ^{k-1}.

Proof: see the bibliographic item 4. This proposition leads to the idea of quality-simulation, which does not necessarily mean computer simulation. Quality-simulation denotes a simulation of quality transition with all (or part) of technomodels which exist in correspondence with QE-domination obtained from complete QE-evolution. Thus, complete QE-evolution can be also regarded as a preparation for modeling of a quality-system with respect to a given quality goal.

Here in order to consider significances of quality-simulation, we shall introduce the concept of realizability.

Definition 6: Realizability
In a quality-system

$$S \subset \prod_A E_a x \prod_B Q_b, \text{ let } Gc \subset \prod_C Q_b$$

be a quality goal; I an arbitrary subset of A; e_I an arbitrary element of E_I. Then, Gc is realizable with e_I in S iff

$$(Se_I)_C \cap Gc \neq \phi$$

holds.

For the technomodels from Proposition 3, if a set $\{q_{\Delta J^k}\}_{k \in In} = \{q_{\Delta J^n}, \ldots, q_{\Delta J^0}\}$ meets $q_{\Delta J^{k-1}} = \Phi^{\Delta J^{k-1}}_{\Delta J}(e_{\Delta I^k})(q_{\Delta J^k})$ for each $k \in Nn$, the set represents a result of quality-simulation with all of them. Then we have the following proposition.

Propostion 4
In a quality-system

$$S \subset \prod_A E_a x \prod_B Q_b, \text{ let } Gc \subset \prod_C Q_b$$

be a quality goal and

$$EVO^n(Gc) = \{((\Delta J^k, \Delta I^k), \Delta J^{k-1}) \mid k \in Nn\}$$

the nth complete QE-evolution with respect to Gc. Set

$$I^n = \bigcup_{k=1}^{n} \Delta I^k.$$

Further, let $e_{I^n} \in E_{I^n}$ be arbitrary and $\Phi_{\Delta J^k}^{\Delta J^{k-1}}(e_{\Delta I^k})$ $(k \in Nn)$ be an $e_{\Delta I^k}$-based technomodel related to ΔJ^k and ΔJ^{k-1}, where $e_{\Delta I^k} = (e_{I^n})_{\Delta I^k}$. Then the following (1) and (2) are equivalent:

(1) Gc is realizable with e_{I^n} in S.
(2) There exists a set $\{q_{\Delta J^k}\}_{k \in I_n}$ that is a result of quality-simulation with the technomodels $\Phi_{\Delta J^k}^{\Delta J^{k-1}}(e_{\Delta I^k})$ $(k = 1, \ldots, n)$ employed and that satisfies $q_{\Delta J^0} \in Gc$.

Proof: see the bibliographic item 4. Some implications of this proposition can be summarized as follows:

(1) Quality-simulation makes it possible to predict whether or not a given quality goal is realizable under an engineering technique applied: in other words, to evaluate the techniques in advance from the viewpoint of realizability of the goal.
(2) If a given quality goal can be achieved at all, quality-simulation makes it possible to forecast beforehand engineering techniques essential to the goal and furthermore what ought to be each quality as a factor or a means under the techniques.
(3) If a given quality goal is not realizable under a certain engineering technique, it can be found that there latently exist technical bottlenecks in the techniques. This makes one recognize or perceive in advance the necessity of detection and settlement of them, and it promotes a prompt solution of technical problems with respect to the goal.
(4) Quality-simulation enables us to evaluate a complete QE-evolution with respect to the efficiency in achieving a given quality goal. In general, there can be several complete QE-evaluations for the goal. In such case, quality-simulation makes one promote advance correction of the QE-evolution from the viewpoint of realizability of the goal. This leads to a wide investigation of engineering techniques.

Furthermore, just in case that a given quality goal is realizable, quality-simulation also makes it possible to analyse and predict each tolerance appropriate for the goal.

Thus, quality-simulation on the basis of complete QE-evolution plays an important role as a way to investigate engineering techniques, quality as a means, and tolerance with respect to a given quality goal.

A SYSTEM FOR QUALITY GOAL-SEEKING

We shall show in Fig. 1 a system to pursue effectively a given quality goal. The activities which constitute the system can be considered as those major and important to quality goal-seeking, and the organization of them is essentially based on the discussion in the two previous sections. The explanation of each STEP and each FEEDBACK is as follows.

Explanation of each STEP

STEP 0: SET A QUALITY GOAL AND A QUALITY SYSTEM

Setting of a quality goal means that the following are specified:

(i) a set of target quality characteristics of a product,
(ii) each set of satisfactory quality characteristic values for each element of the above set.

Of course, it is necessary that a quality goal reflects a customer's needs in improvement of an existing product or in development of a new product. On the other hand, setting of a quality-system gives the framework in which the following STEPs are executed.

It is assumed that the given quality goal does not change in this system.

STEP 1: EXECUTE A COMPLETE QE-EVOLUTION

Through the execution of a complete QE-evolution with respect to the quality goal, causal relationships among quality characteristics and also between technical factors and quality characteristics are made clear. Furthermore, all engineering techniques related to the quality goal, based on their causal relationships, are clarified and systemized in correspondence with each quality characteristic.

In this step, it is necessary that the execution of a complete QE-evolution is based on the accumulation of engineering knowledge at the present day, theoretical and/or statistical analysis and so on.

STEP 2: SELECT TECHNIQUES APPLIED TO EACH QUALITY CHARACTERISTIC

Engineering techniques applied to each quality characteristic are selected among the techniques which have been clarified and systemized in STEP 1. In that case, it is highly desirable that one of the best techniques that is empirically known is selected.

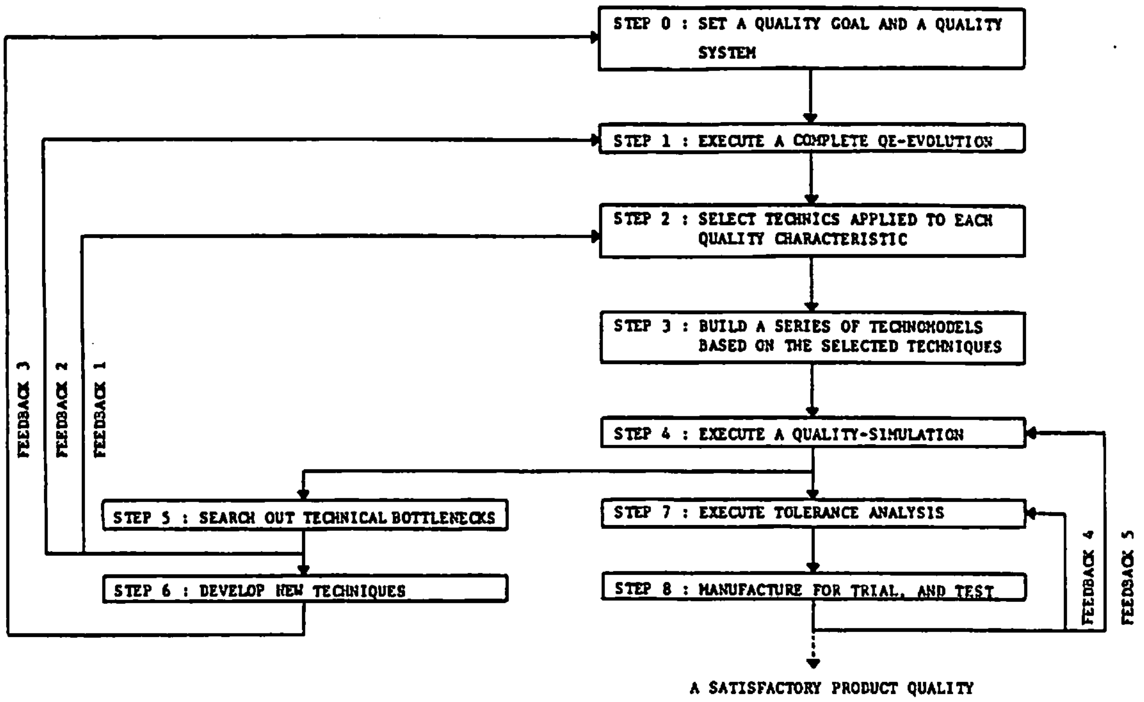

Fig. 1. A system for quality goal-seeking.

STEP 3: BUILD A SERIES OF TECHNOMODELS BASED ON THE SELECTED TECHNIQUES

Each technomodel based on the selected techniques is built by means of adequate modeling methods. In that case, the input and output variables are decided on the basis of the causal relationships which have been made clear in STEP 1.

STEP 4: EXECUTE A QUALITY-SIMULATION

A quality-simulation is executed by means of a series of technomodels built in STEP 3 and adequate simulation methods, and it is predicted whether or not the quality goal is realizable under the techniques selected in STEP 2. If not realizable, proceed to STEP 5 because there latently exist technical bottlenecks. On the other hand, if realizable, an adequate quality is predicted for each quality characteristic as a factor, and proceed to STEP 7.

STEP 5: SEARCH OUT TECHNICAL BOTTLENECKS

Technical bottlenecks are searched out and clarified among a series of the techniques selected in STEP 2.

STEP 6: DEVELOP NEW TECHNIQUES

New engineering techniques are researched and developed in order to achieve the quality goal.

STEP 7: EXECUTE TOLERANCE ANALYSIS

A series of tolerances suitable for the quality goal are analysed and predicted. In that case, it is desirable, if possible, that present process capability is clarified for each quality characteristic and it is utilized.

STEP 8: MANUFACTURE FOR TRIAL AND TEST

Trial products are manufactured on the basis of the techniques by which the quality goal is realizable, the quality predicted for each quality characteristic, and the predicted tolerances. Furthermore, it is checked whether or not they really achieve the quality goal. That is, the validity of the above prediction is verified in this step.

Note: although not written clearly in Fig. 1, each activity and its result should be reviewed in each STEP.

Explanation of each FEEDBACK

FEEDBACK 1:

In order to solve the technical bottlenecks, other engineering techniques are reselected among the techniques clarified and systemized in STEP 2.

FEEDBACK 2:

When all techniques clarified and systemized in STEP 2 are examined and in them there are not engineering techniques by which the quality goal can be achieved, other complete QE-evolution is executed if possible.

FEEDBACK 3:
Development of new engineering techniques leads to a change of the quality-system stated in STEP 0. In FEEDBACK 3, a quality-system with the new techniques is stated.

FEEDBACK 4:
The tolerances predicted in STEP 7 are re-examined and altered in comparison with the actual results.

FEEDBACK 5:
The qualities predicted in STEP 4 are reinvestigated and altered in comparison with the actual results.

Note: FEEDBACK 1 and FEEDBACK 2 are executed when there are left engineering techniques to be examined. FEEDBACK 1 is prior to FEEDBACK 2. FEEDBACK 4 and FEEDBACK 5 are executed when trial products do not really achieve the quality goal. FEEDBACK 4 is prior to FEEDBACK 5.

A feature of this system, which is especially worth mentioning, is to detect organizationally technical bottlenecks and get rid of them as quickly as possible.

RELATION CHART SYSTEM

From a practical viewpoint, each STEP in Fig. 1 is usually put into practice by the participation not of an engineer or a department in a company but of all engineers or departments concerned. Therefore, in the practice at each STEP there can be diverse minds with respect to the efficiency in the pursuit of a given quality goal. In order to practice successfully each STEP under such situation, it is required to coordinate well the diverse minds concerned. Further, in order that the system pursues a given quality goal effectively as a whole under the situation, it is required that a series of activities are consistent. The activity at each STEP is quite complicated and produces much information. This influences the efficiency of quality goal-seeking. Especially, the review of much information involves a great difficulty. In order to pursue efficiently a given quality goal, it is required to facilitate the practice of each activity and each review as much as possible.

The above requirements imply that it is essential to prepare a certain kind of tool for such coordination, consistency and facilitation. However, it is very difficult to give a universal tool which can cover all kinds of products. We give here such a tool within the range of mechanical assembled products as general as is possible. The tool is shown in Fig. 2. Its form is based on 'Relation Chart System (R.C.S.)' [2] and the system in Fig. 1, and it is the expansion of R.C.S. We again call this new tool R.C.S. The explanation of arrows and each item in this R.C.S. is shown in Fig. 2.

The basic structure of this R.C.S. is based on the recognition that mechanical assembled products are generally produced by engineering techniques through stages of raw materials, roughly-formed materials, parts, assemblies and finished products. These stages are respectively numbered by 1, 2, 3, 4 and 5. The number of finished product stage might be more than 5 or less depending on situations. A quality goal is written in A^5 and G: target quality characteristics in A^5; satisfacotry values in G. A QE-evolution is conducted down through (in Fig. 2, upwards) finished products, assemblies, parts, roughly-formed materials to raw materials with respect to the given quality goal. Quality characteristics and technical factors at each stage are filled in A^K $(K = 1, 2, 3, 4)$ and F^K $(K = 1, 2, 3, 4)$, respectively. The dominative relationships are expressed by arrows and all engineering techniques are clarified and systemized in E^K $(K = 1, 2, 3, 4)$. New engineering techniques developed are also gathered in the same places. Engineering techniques selected are filled in E^K_* $(K = 2, 3, 4, 5)$. Technomodels are gathered in M^K $(K = 2, 3, 4, 5)$. The quality and tolerance predicted through a quality-simulation are written in X^K $(K = 1, 2, 3, 4, 5)$, so are the actual ones. The present process capability is gathered in C^K $(K = 1, 2, 3, 4)$. Technical bottlenecks, if any, can be marked in E^K_* $(K = 2, 3, 4, 5)$.

A PRACTICAL APPLICATION

Japan Steel Works Hiroshima Plant (JSW) is one of the companies which produce industrial machines according to each order from customers and which takes the form of multikind and small-quantity production.

JSW has been developing 'Ambitious Goal-Seeking (AGS)' activity for some primal products since it introduced company-wide quality control in 1977. That is, aiming at the best quality of those products in the world, JSW has been setting up challenge goals for quality control and R&D, and it has been company-widely enforcing several improvement activities with respect to quality, cost and delivery dates.

However, each of the sections concerned had a tendency to practice the activity with little consideration of influences to the others: in other words, in

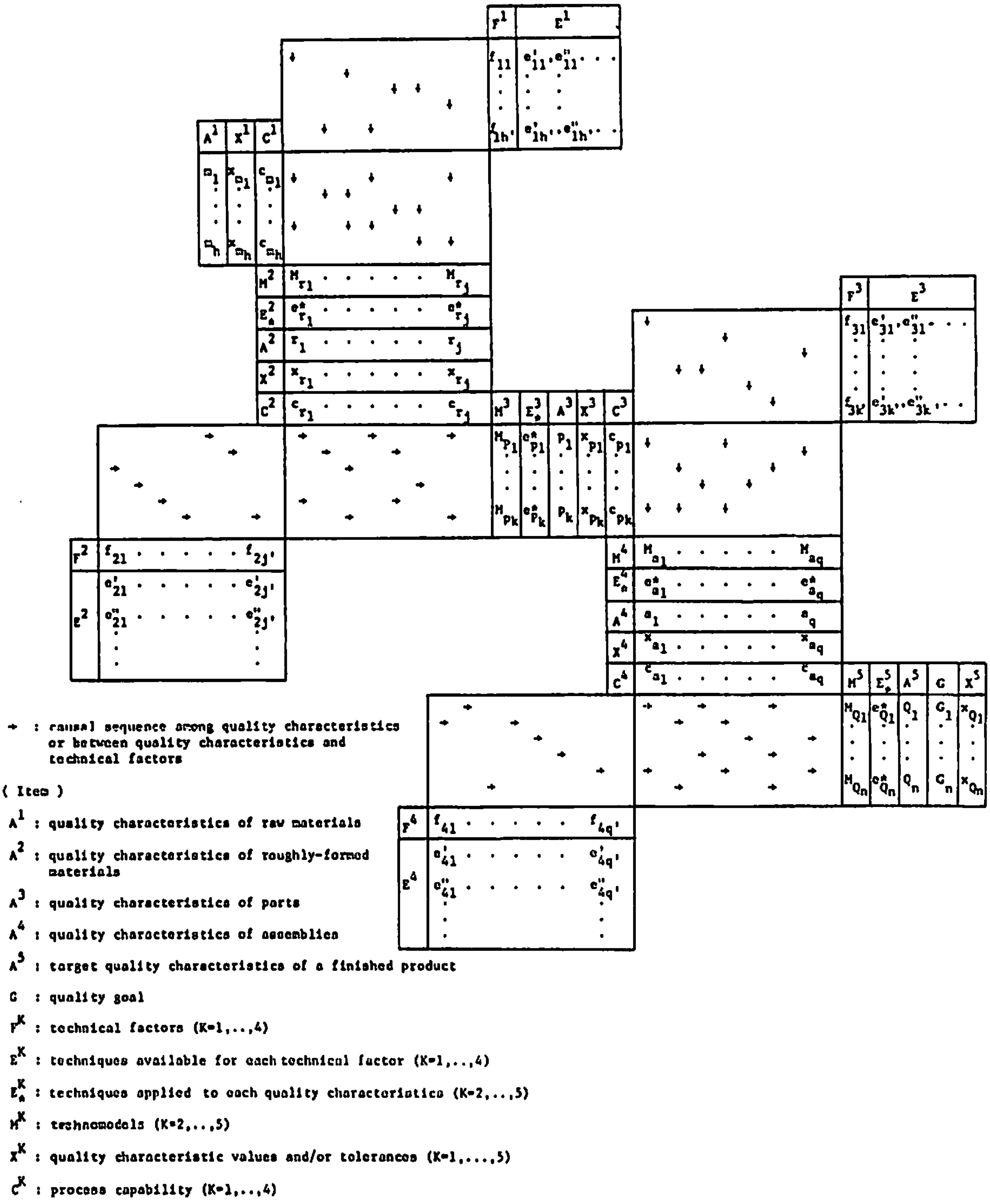

Fig. 2. Relation chart system.

accordance with each individual concern. Further, it was often the case to start on production without adequate prediction of realizability of a given quality goal, enough investigation of countermeasures, and so on. Such a situation often fails to realize products to meet the users' needs and also to develop well the technical power which potentially the company has.

The methodology discussed in the previous sections was introduced as a foundation to overcome such problems: and it was applied to the pursuit of a quality goal given to an extruding machine (a plastic processing machine), which is a primal product of JSW. The activity has been put into practice by means of 'Quality Forecasting Chart (QFC)' and 'Quality Characteristics Relation Chart (QCRC)' named by JSW. These charts are essentially based on R.C.S. They are briefly mentioned as one of the examples showing how our methodology has been applied by JSW. Therefore, the contents of them are not described in detail. Further, how to make them is not discussed, either.

QFC is shown in Fig. 3 and the explanation of each item is as follows.

Customer's needs. Fill out first hand information about customer's requirements, e.g. High Extruding Volume and Long Life are written.

Required quality. Fill out quality characteristics, characteristic items and concrete values, e.g. Endurance Performance, Cylinder and Screw, and 15 and 10 years are written.

Comparison with competitors. Fill out achieved qualities in comparison with those of competitors: the qualities achieved by JSW are written in comparison with those of company A.

Discrimination of importance. Rank the importance of quality characteristics of Required Quality: quality characteristics which larger numbers are assigned to are more important than those which smaller numbers are assigned to.

Planned quality. Fill out planned quality characteristic values: quality goals to be pursued are determined on the basis of information from Required Quality, Comparson with Competitors, Discrimination of Importance, JSW's policy, etc.

Basic function. Clarify basic functions of components: Resin Processing in column I is one of functions; this function is described by several functions such as Resin Receiving, Resin Forwarding, etc. written in column II; each function in column II is also described by functions written in column III; in this way, basic functions are clarified.

Designed quality characteristics. Fill out designed quality characteristics only (their details are evolved in QCRC as shown in Fig. 4): e.g. Cylinder Configuration, Screw Configuration and Surface Treatment are written.

Possessed techniques table. Clear up all techniques which exist in designing and manufacturing departments in correspondence with Basic Functions: e.g. Indicating Method of Gilt and Techniques for Gilding are written for Corrosion Resistence.

NE items. Select the techniques which will not achieve Planned Quality out of all of them (such techniques are called 'Neck Engineering (NE)' in JSW): e.g. Insufficiency of Extruding Volume is written.

Techniques selection table. Seek out every available technique in the world; collect the information about each of them; and then evaluate them in order to solve NE Items: e.g. Settlement of Scale-Up Coefficient is selected.

R&D plan table. Pick up the best techniques from Techniques Selction Table and make their development plans.

External loading factors. Fill out conditions of designing and values of each external loading: e.g. Flight Surface Pressure and 300 kg/cm^2 are written.

Test code. Fill out test items which must be confirmed after receipt of the order or before delivery of the products: e.g. Test of Screw's Resistence to Wear is written.

Parts construction. Fill out all parts of the product assorted into components: e.g. Hopper Cylinder and Screw are written.

The explanation of each item in QCRC is as follows (the alphabet of each item corresponds to that of each part in Fig. 4):

(A) *Quality characteristics (initial)*: fill out the quality characteristics and their values of each component which are derived from Planned Quality.

(B) *Using conditions/designing conditions*: fill out conditions of using and designing.

(C) *Characteristic limits: characteristic limit values*—fill out the limit of each quality characteristic value; *marginal time*—fill out the marginal time both of MTBF (Mean Time Between Failure) and of MTTF (Mean Time To Failure).

(D) *Assembly characteristics*: fill out quality characteristics of assemblies and their values.

(E) *QA-table evolution*: fill out qualities necessary for parts and process capability corresponding to each of them.

(F) *Production techniques evolution*: fill out all technical conditions of pre-processing treatment and of processing; and fill out capability of facility corresponding to each of them.

(G) *Raw materials evolution*: fill out quality characteristics of materials and criteria for inspections.

JSW uses two types of QFC which have the same format and different contents. JSW produces a series of extruding machines: and hence one chart contains only common items of those extruding machines. This chart is called the 'Common Chart'. The other is made for individual extruding machines and it contains both common items and special items of each extruding machine. This chart is called the 'Individual Chart'. The Individual Chart is made up on the basis of the Common Chart. If a quality improvement for one extruding machine is achieved and belongs to common items, then quality improvements for other extruding machines becomes possible through the Common Chart.

A larger-scale extruding machine has been demanded year by year. These charts were applied to

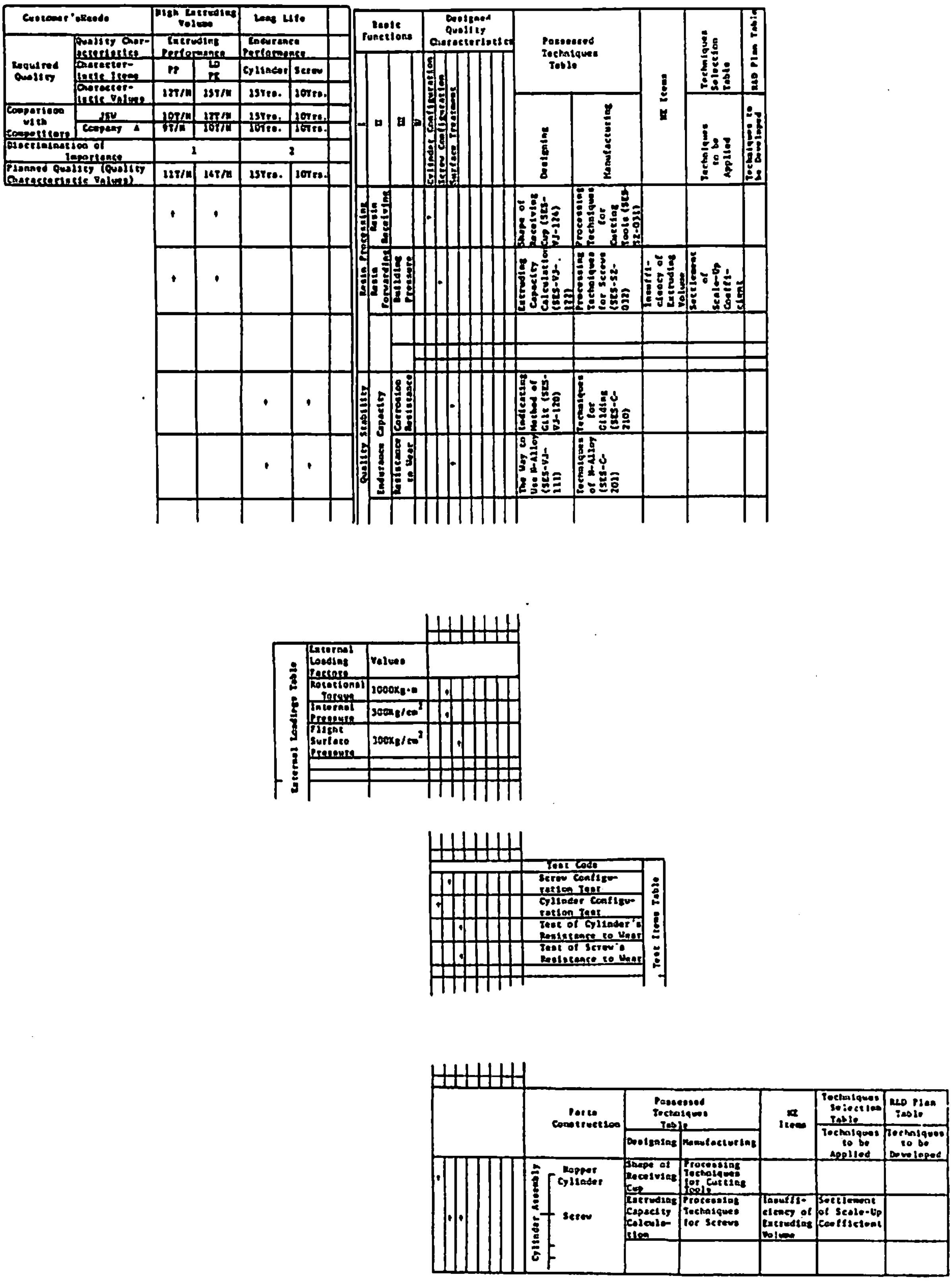

Fig. 3. Quality forecasting chart (extruding machine).

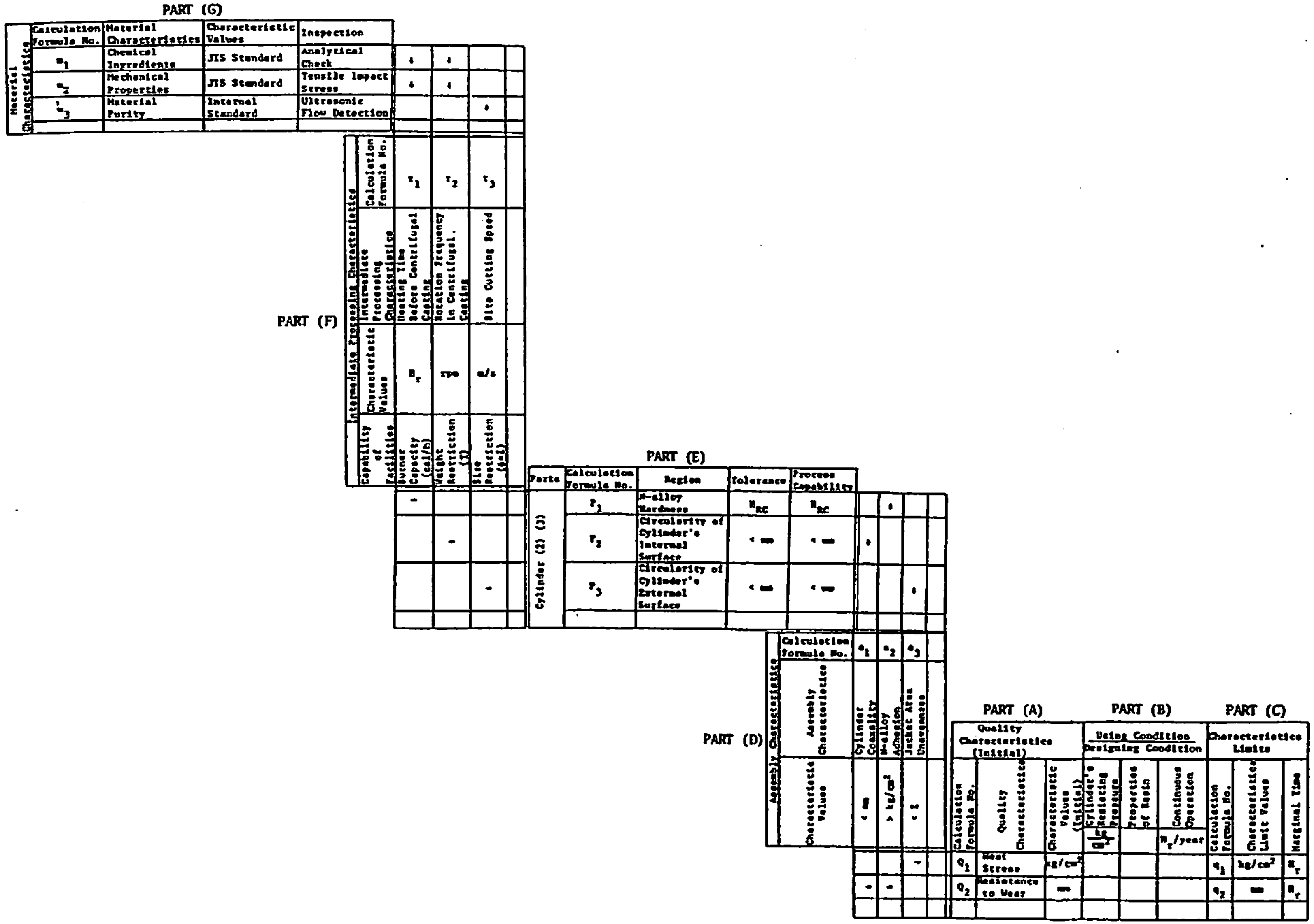

Fig. 4. Quality characteristics relation chart.

development of an extra-large-scale cylinder which is an important part of larger-scale extruding machine. Through the application of these charts, a smooth settlement of technical problems and much reduction of development period could be realized. Hence, JSW could keep up with the user's construction plans and consequently succeed in receiving or taking orders.

At present, these charts are applied to each mechanical device of every product that JSW takes orders for. They clarify and systemize the relations between customer's requiring qualities and possessed techniques: and bring such good results as prompt solution of technical problems, shortening of development period, cost reduction, etc.

CONCLUSION

We have presented a methodology for quality goal-seeking and coordination. The theoretical part has been developed within the framework of mathematical general systems theory [5], and so the results are applicable to other goal-seeking activities.

When the methodology is applied to quality goal-seeking activities, such effects as the following can be expected.

1. In the product development stage, quality goal-seeking activities can be conducted organizationally and systematically.
2. What is the problem and what action should be taken can be clarified with respect to quality goal-seeking. Especially, the prompt settlement of technical bottlenecks is promoted.
3. Quality control activities of departments in a company (sales, designing, manufacturing, supplying, inspection, research, etc.) can be coordinated and come into coherence.
4. Exaltation of quality-mindedness, reduction of product development period, etc. can be achieved with more ease.

In fact, the methodology is practiced in Japan Steel Works Hiroshima Plant, and the company has obtained excellent results.

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