

**University of West Hungary  
Sopron**

Main points of the dissertation

**“Optimisation of manufacturing processes by using desirability models in quality engineering”**

written by  
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**Scientific discipline:** Material science and technology

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## ***1 Research goals and scientific premises***

Constructing a product in the industry, or a regular service is usually not obvious from the design. Depending on the kind of profession there is an opportunity to choose how the design will be implemented. Often the number or the nature of the technological steps can be chosen, but the production properties, the internal indices of a service will be nearly always set uniquely (Koczor(1999)).

Using quality control systems we try to handle the interactions of process parameters. The main reason for this activity is not only to avoid harmful influences or implementing given goals. We would like to select the optima that corresponds to the current case, using past experience and all this quick enough for being able to serve the decision making.

The different quality requirements need different implementations of the process. To achieve this, we have to use a special technique that is able to handle several requirements at the same time. This technique has elements that can be handled using analytical functions.

The dissertation describes these kinds of decision problems, specifically the desirability models (Harrington (1965)), their possible applications and extensions. Desirability models are able to manage requirements that contradict each other. They indicate the importance of each parameter by a weighting mechanism, and describe the process using multivariate functions.

The desirability models in their standard form aren't able to treat the statistical properties of a process. We aimed to extend the model in this direction: we suggested a model that is based on a loss function and is calculated using the probability of not meeting a given target value. In order to not lose generality, we can calculate some of the process properties in their unchanged form.

Acknowledging the advantages of the existing desirability models, the flexibility of them enables some changes and extensions to make them more usable for treating certain problems.

In order to increase usability of the desirability model in our case (similarly to Derringer(1994)) we tried to use a complete methodology:

- a visual tool that shows quality levels and supports decision making, and
- a data exclusion mechanism that weights and archives data.

The suggested desirability functions were applied to a spinning-mill system, and compared to the results from the Derringer-Suich (1980) model.

### ***1.1 Research goals***

In the dissertation we tried to concentrate on the followings (summarising the above points):

1. How the desirability functions based on the probability of not meeting a target value fits into the desirability model philosophy and its calculation.
2. Conclusions from the results regarding real-life applications.
3. Data processing methods:
  - A data exclusion mechanism for archiving data and describing trends;
  - A visual tool that makes it possible to compare the results of the optimisation.

- An expert system built on the desirability model, and an application for a spinning-mill system.
- Generalisation of the desirability model to other mass-manufacturing processes.

## ***1.2 Methods of experiments***

To compare the desirability models and to prove the usability of the extended model we used a test case. The test case was based on real-life data from a spinning-mill.

The coherent rows of properties made us possible to estimate the relationship between the response variables and the input variable, also the definition of constraints and then the optimisation.

The data collection, the definition of constraints and the optimisation all was made in the expert system that is explained in the theses.

## *2 Contributions to knowledge*

Some variants of the desirability function are used widespread for optimising processes. As mentioned in point 1, there are extensions that keep generality and give some new idea to the original model, and extensions that amend the optimisation itself (e.g. Castillo – Montgomery – McCarville (1996)).

We tried the former so that when considering cases where not meeting the target value influences the desirability function decisively, we're minimizing the probability of not meeting the target. We constructed a desirability function for such cases.

A general expert system was suggested that supports raising the problem, and a visual tool that supports the comparison of the different desirability functions (also the comparison of the starting/optimal solution or the different solution steps). The advantage of the tool is that it shows visually which property puts down the others.

A data exclusion mechanism was also suggested, which enables to describe trends. It makes it possible to filter out extreme values that will probably never happen again. It is an easy way to describe how a given process property changes in time.

For proving the usability of the general expert system in practice we applied our model to a spinning-mill where we got data from passive experimentation. We compared two models regarding their optimal solutions and found that using the modified functions is feasible, and our model fits into the requirements and philosophy of the original desirability model. The data collection and maintenance, addition of constraints and the optimisation proceeded in an add-in to Microsoft Excel - developed by us.

Based the applied desirability model and the spinning-mill system we determined that the generalisation of the methodology to all mass-manufacturing processes is feasible where the constraints and the compromise of the process properties can be treated in a similar way.

### 3 *Main points of the dissertation*

#### 3.1 *Definition of the terms used*

In the dissertation we extended the definition of *desirability functions*. We consider Harrington's original approach as a methodology that can fulfil different customer needs at a time. This idea can be extended in two ways:

1. We can define desirability as a quality management concept, extending the original definition to objective and measurable product parameters, that can be handled from the management point of view as well.
2. We can bring non-measurable properties into the model ('feelings'), e.g. motivation or the exact level of customer satisfaction.

Within the dissertation we only use the first extension.

We define *risk* as follows: risk is the function of the probability and the cause of an event.

$$K(A)=P(A)V(A)$$

This interpretation of risk is used in the modified desirability functions when we create a desirability function as the product of a probability and a loss function.

We defined a data *exclusion mechanism*. Using the mechanism it is possible to

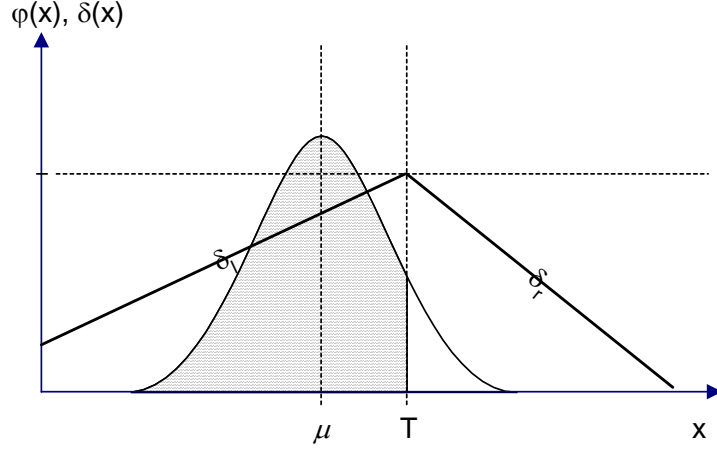
- keep older data in a compressed form (i.e. by including the average in the data set)
- exclude periodic or extreme values from the model, so it can help determining more realistic process trends.

#### 3.2 *The main points explained*

##### *Thesis 1: Defining desirability functions based on loss functions*

**We developed a new set of desirability functions using the probability of the difference between the target and actual value of a quality property.**

These functions are based partially on a risk-analysis methodology worked out by us, and partially on loss-functions (linear functions or ones similar to the Taguchi quadratic loss function). The loss functions – called *helper desirability functions* in our case – have the value of 1 if meeting the target, they decrease otherwise (**Figure 1**).



**Figure 1: Probability of not meeting the target, using linear helper desirability functions**

Definition of the *helper desirability functions*: the  $\delta(\mathbf{x})$  function has its maximum at the target and decreases if not meeting the target, with an image set of  $W_f = [0, 1]$ .

If not meeting the target causes a linear loss, the function can be calculated as follows:

$$\delta_{il}(\mathbf{x}) = \begin{cases} 1 + k_{il}(\hat{y}_i(\mathbf{x}) - T_i), & T_i - \frac{1}{k_{il}} \leq y_i \leq T_i \\ 0, & \text{otherwise} \end{cases}$$

for the left side and

$$\delta_{ir}(\mathbf{x}) = \begin{cases} 1 - k_{ir}(\hat{y}_i(\mathbf{x}) - T_i), & T_i \leq y_i \leq T_i + \frac{1}{k_{ir}} \\ 0, & \text{otherwise} \end{cases}$$

for the right side.

The desirability functions will be the sum of each side's desirability:

$$d_i(\mathbf{x}) = \delta_{il}(\mathbf{x})\Phi_{\mu_i, \sigma_i}(T_i) + \delta_{ir}(\mathbf{x})(1 - \Phi_{\mu_i, \sigma_i}(T_i))$$

The composite desirability, including weighting, can be calculated as follows:

$$D_\delta = \sqrt[q]{\prod_{i=1}^q d_i^{w_i}},$$

where

$$S = \sum_{i=1}^q w_i.$$

**Thesis 2: Application of the desirability model to co-operate between the technical and the management system**

**We developed a new method for the co-operation of the technical<sup>1</sup> and the management system<sup>2</sup>. This method supports the application of the desirability concept on the system.**

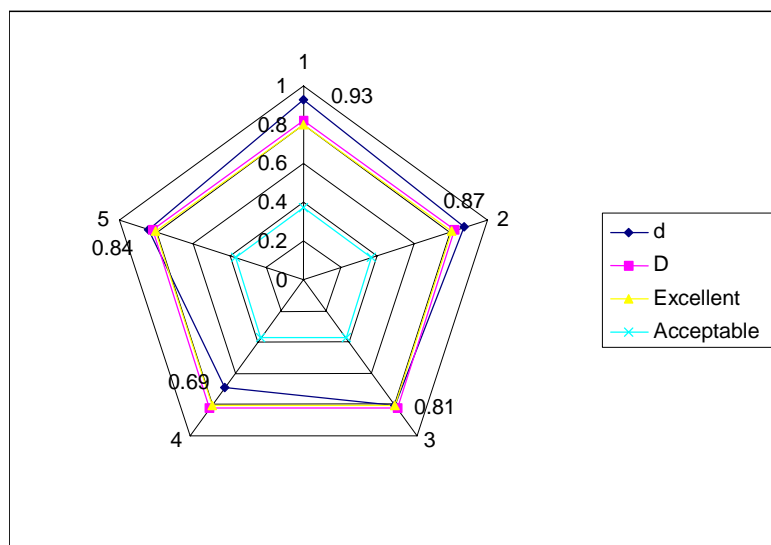
*This has been done by:*

- 1. a visual tool that supports decision making, and*
- 2. the definition of an expert system based on the desirability model.*

A visual tool has been developed for helping the demonstration of the optimal values. This tool shows the values in the form of a polygon and makes it possible to visualize quality levels, desirability values and probabilities of not meeting the target (see *Figure 2*).

The advantage of this tool is that desirability values can be compared easily, thus supporting management decisions.

The general expert system based on the desirability concept (*Figure 3*) includes data recording and selecting which raw material and which material properties and other measurable properties should be included in the model. It helps to define the actual problem, to define the constraints and to check if an optimal solution for a given case exists at all.



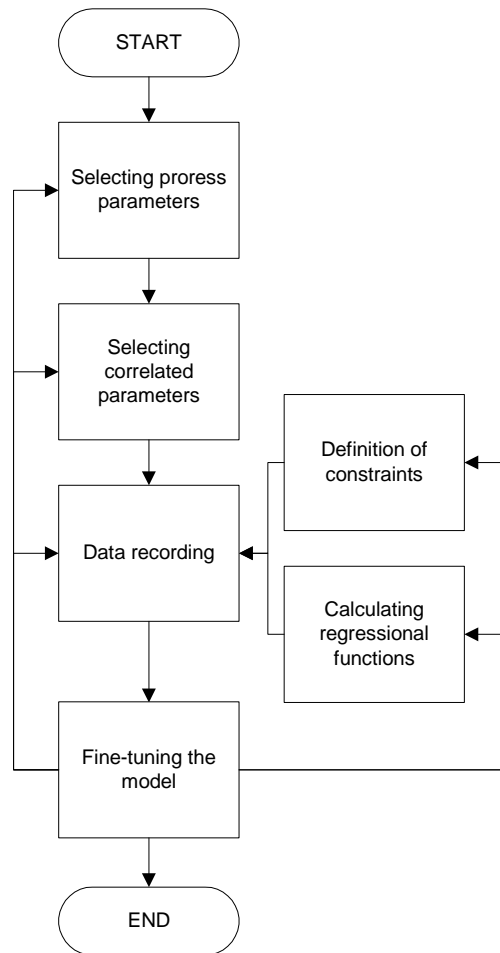
**Figure 2: Polygon showing optimal desirability values and quality levels.**

The output of the expert system is the ready model with all data and constraints.

<sup>1</sup> A technical system can be interpreted as a system that aims the amendment of physical and chemical properties.

<sup>2</sup> Management means everything needed to run a successful company. The technical system is part of this.

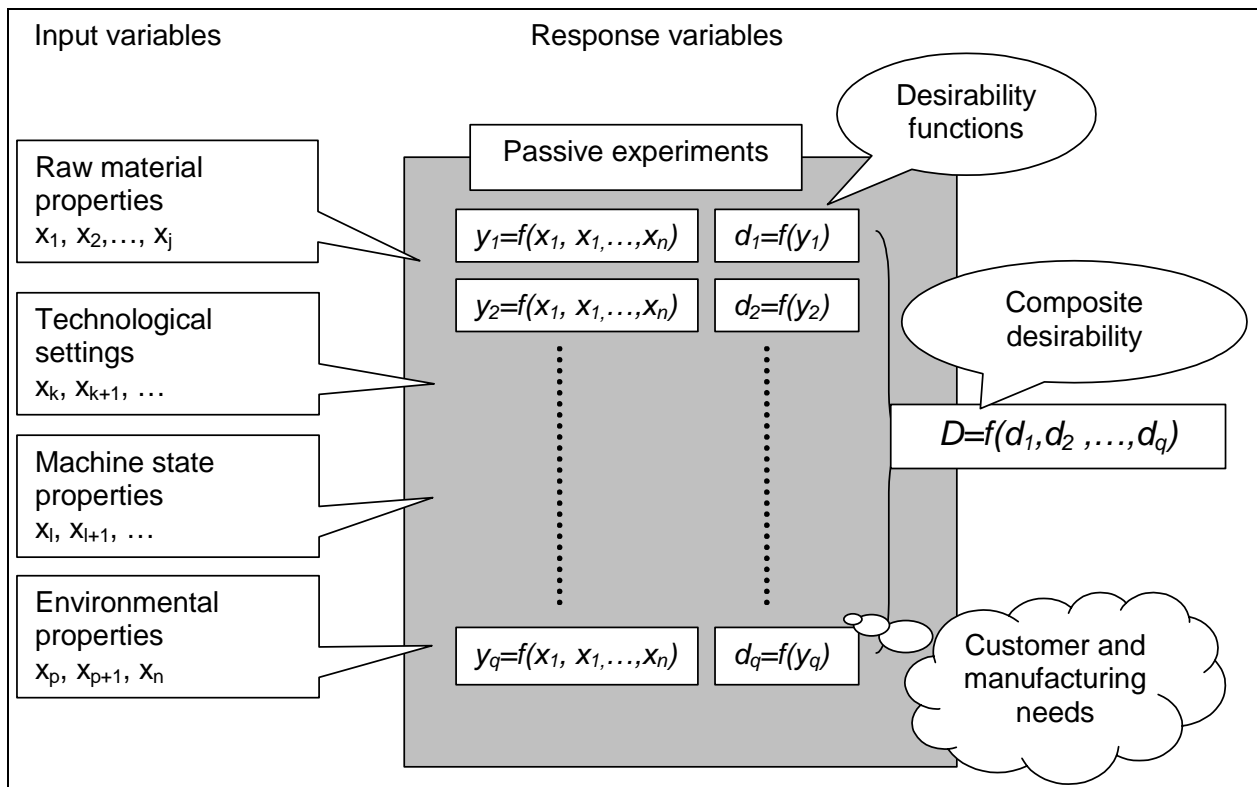




**Figure 3: The general expert system based on the desirability concept**

*Using this expert system for a spinning mill production example we introduced the method and made it applicable for process optimisation.*

*While the output of the general expert system is the problem definition with all data and constraints, the output of the applied expert system is the optimal solution that can be used when making decisions or interventions regarding the manufacturing process (Figure 4).*



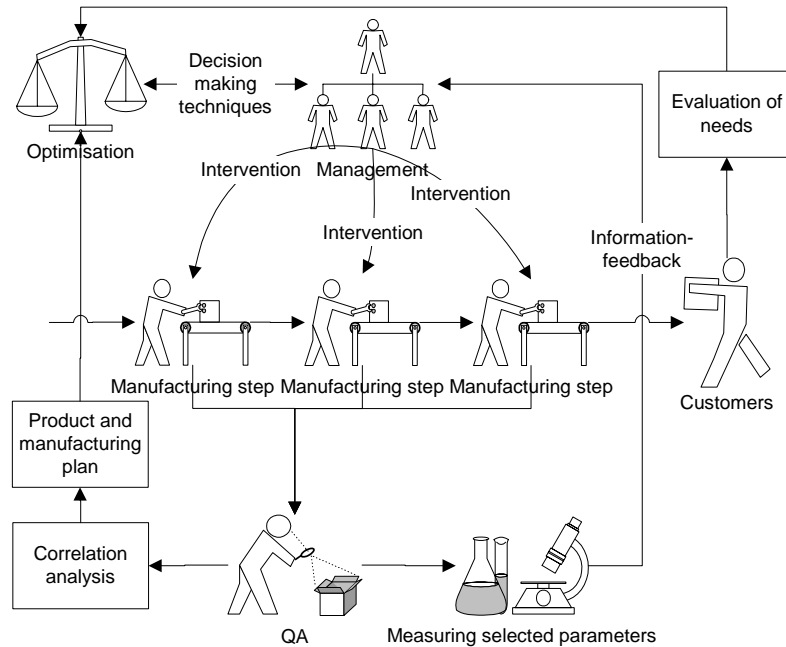
**Figure 4: The spinning-mill expert system**

The spinning-mill expert system consists of the followings:

- Definition of the input variables,
  - raw material properties
  - machine state properties,
  - technological settings, and
  - environmental properties,
- definition of the response variables,
- calculation of the function between input variables and responses based on passive experiments,
- calculation of the desirability functions from the regression functions and from the customer and manufacturing needs,
- calculation of the composite desirability and optimising it.

The spinning-mill expert system can help when *parameterised values* and *importance* of customer needs are to be measured (Figure 5).

To get the parameterised values the customer's needs have to be converted to numeric values. This means that the type and value of specification limits have to be defined.



**Figure 5: Treating the expert system from the management decisions' and customer needs' point of view**

The importance of variables is included in the concept by means of a weighting mechanism that is based on pairs of the calculated quality level and the measured value of the variable.

The method can be applied very flexible, whereas the *a priori* knowledge about the manufacturing process is very important for being able to get interpretable and sensible results. The optimisation can happen iteratively until we reach a certain quality level.

Problem handling based on the desirability model can be used to achieve increased satisfaction for customer groups. The aim of the method is to determine correlations between responses and input variables, when we can modify the inputs. However, not all responses can have their best value at the same time, so we have to reach a compromise that leads to the highest customer satisfaction under the given constraints.

Weighting is our decision: we can define weights based on objective and subjective elements, using the customer satisfaction information collected.

### ***Thesis 3: Extending the tools of the desirability model***

*This is the generalisation of Thesis 2. The generalisation is adequate because mass-manufacturing processes with the same constraints can be handled the same way from the viewpoint of the product properties and the compromise between the response variables.*

As a proof we can collect the common foundations of *design of experiments* (DOE) :

- the variables describing the process can be divided into input variables and response variables,
- the function between the responses and the input variables are to be calculated after determining the type of the correlation between them;
- we aim to get to the optima through the optimisation of these functions.

In our case we analyse only mass-manufacturing processes that provide *enough data* with an appropriate *frequency*.

If we treat the desirability concept as a special case of DOE tools, the former can be extended – when meeting some further assumptions – to all manufacturing processes where applying DOE is adequate. The assumptions come from the nature of the desirability model, so the process should have the following additional characteristics:

- response variables contradict each other in some cases so a compromise solution has to be searched for,
- we can determine specification limits and/or target values for the responses.

When treating the desirability model as a management tool, from the *conceptual*, *innovative*, *stabilisation* and *stable* phases of processes it can be classified mostly as the latter.

## 4 References

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