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VOLUME I

Edited by

» Daniel Torres-Salinas

• EC3 Research Group (Evaluación de la Ciencia y la Comunicación Científica)
Universidad de Granada, Granada, Spain
• Centro de Investigación Médica Aplicada (CIMA)
Universidad de Navarra, Pamplona, Spain

» Henk F. Moed

• Centre for Science & Technology Studies (CWTS)
Leiden University, Leiden, the Netherlands

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VOLUME I

VOLUME II

Response Surface Methodology and its Application in Evaluating Scientific Activity[1]

Evaristo Jiménez-Contreras*, Rafael Bailón Moreno*, Daniel Torres-Salinas**, Rosario Ruiz Baños*, Rafael Ruiz-Pérez*, Mercedes Moneda Corrochano* and Emilio Delgado López-Cózar*

*evaristo@ugr.es
Departamento de Biblioteconomía y Documentación, Universidad de Granada, Granada-18071 (Spain)

**torressalinas@gmail.com
Centro de Investigación Médica Apicada (CIMA), Universidad de Navarra, Pamplona-31008 (Spain)

Abstract
The possibilities of the Response Surface Methodology (RSM) has been explored within the ambit of Scientific Activity Analysis. The case of the system "Departments of the Area of Health Sciences of the University of Navarre (Spain)" has been studied in relation to the system "Scientific Community in the Health Sciences", from the perspective of input/output models (factors/response). It is concluded that the RSM reveals the causal relationships between factors and responses through the construction of polynomial mathematical models. Similarly, quasi-experimental designs are proposed, these permitting scientific activity to be analysed with minimum effort and cost and high accuracy.

Keywords
evaluation of scientific activity; response surface methodology; experimental design

Introduction
The analysis of scientific activity focusing on the economic input/output model—especially when dealing with institutions—is classical and almost the foundation of scientific evaluation (Martin & Irvine, 1983). This model implies that the system under study has easily defined borders affected by a set of factors or variables called *inputs* and which represent the resources of the system (funding, researchers, equipment, etc.). This system in turn generates or responds to products resulting from their scientific activity, called *outputs*, such as publications or patents.

The relationships which link inputs with outputs are complex and difficult to describe with elemental mathematical models. Therefore, the need arises for tools that are capable of more complex modelling and that achieve maximum refinement of the role of each variable in the system as well as the of synergetic and/or antagonistic interrelationships between the same variables.

The Response Surface Methodology (RSM) emerged in the 1950s (Box & Wilson 1951; Box & Hunter 1951) within the context of Chemical Engineering in an attempt to construct empirical models able to find useful statistical relationships between all the variables making up an industrial system. This methodology is based on experimental design with the final goal of evaluating optimal functioning of industrial facilities, using minimum experimental effort. Here, the inputs are called factors or variables and the outputs represent the response that generates the system under the causal action of the factors or variables. In recent years it is being applied successfully in other scientific fields such as biology, medicine, and economy. Myers et al. (2004) has exhaustively reviewed the literature in the sense, describing the developments and applications of this methodology. Very recently, RSM has been used even to validate new experimental methods (Jurado et al. 2003)

Objectives
In this presentation, we seek to explore the possibilities of the Response Surface Methodology within the scope of the analysis of scientific activity.

[1] This study is part of a project funded by the initiative of the *Centro de Investigación Médica Aplicada* de la *Universidad de Navarra.* Color Version of all figures are available from the authors.

Figure 2. System Departments of Health Sciences of the University of Navarre

For this, we shall consider the case of the system "Departments of Health Sciences of the University of Navarre". The University of Navarre will be represented by a system in which the factors (inputs) are the human resources as well as the economic resources while the response (outputs) are the scientific production *(Figure 2)*

Materials and methods

Description of the method of the response surfaces

The designs of the response surface methodology (RSM) are those in which problems are modelled and analysed; in these problems the response of interest is influenced by different variables. The RSM is widely used as an optimisation, development, and improvement technique for processes based on the use of factorial designs—that is, those in which the response variable is measured for all the possible combinations of the levels chosen of the factors or variables. The main effect of a factor is defined as the variation in response caused by a change in the level of the factor considered, when the other ones are kept constant. There is an interaction (dependence) between the variables when the effect of one factor depends on the behaviour of another. The application of the RSM becomes indispensable when, after the significant factors affecting the response have been identified, it is considered necessary to explore the relationship between the factor and dependent variable within the experimental region and not only at the borders. Response surfaces are recommended for these types of factorial designs for their effectiveness and quick execution. This consists of correlating the *k* variables put into action through a second-degree polynomial expression of the following form:

$$y_{obs} = b_0 + \sum_{i=1}^{k} b_i x_i + \sum_{i=1}^{k-1} \sum_{j=i+1}^{k} b_{i,j} x_i x_j + \sum_{i=1}^{k} b_{i,i} x_i^2 + e$$

where y_{obs} is the dependent variable, and x_i the factors or variables with which we wish to correlate it. The expression contains a first-degree term that represents a linear relationship considered as the principal, another term in which the variables cross each other to represent the influence of some over others, and finally a second-degree term that refines the previous one and gives maximums and minimums—i.e. optimal values of the dependent variable. The symbols b_0, b_i, $b_{i,j}$ are constants and e a term of error or residual between the observed and calculated value. The experimental values are adjusted to the above equation by a polynomial regression and the usual statistics can be used to determine the goodness of the fit.

The SRM implies, apart from the use of a second-degree polynomial model, a very reduced experimental design called Central Composite Design (CCD). The CCD is formulated on the basis of the factorial designs adding the star points and the central point, and three types of different structures can be used (Figure 3).

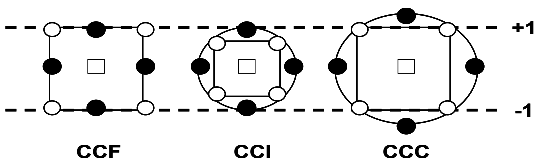

Figure 3. Different structures of CCD: central side (CCF), inscribed (CCI) and circumscribed(CCC)

Regardless of the structure of the composite central design that is used, for each factor or variable, experiments will be performed for 5 different values or levels: -□, *-1*, *0*, *+1* y +□. Therefore, not all the combinations possible will be made, but rather only those that fulfil a geometric CCD design, i.e. only the points indicated.

In certain applications, the variables cannot take any combination of values, due to certain restrictions. Figure 4 is an example of an experimental window where only in the shaded area, limited by restricting lines, is the design feasible. To facilitate the setting up and fit of the model, a new group of components are defined, these being called pseudocomponents.

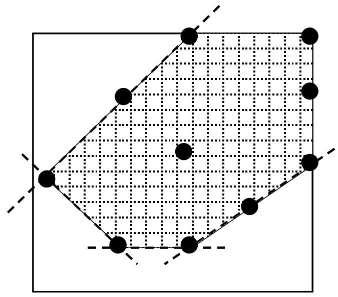

Figure 4. Example of design with restrictions

From the resulting values, for each of the variables, the coefficients of the polynomial equation are determined (b_0, b_i, $b_{i,j}$) and the equation can be simplified according to the influence of the factors in the final response. The resulting equation is used as a model of a given system to determine the response of y as a function of the different values of x_1 and x_2 within the defined area in the CCD.

Material: Area of Health Sciences of the University of Navarra
An evaluation was made of the international scientific production of 50 departments of the University of Navarra (UNAV) related to Biomedicine and Health Sciences in the period 1999-2005. The production data and citations were taken from the Web of Science and those of impact from the Journal Citation Reports corresponding to this period. The information on economic and human resources was provided by the this university. Table 1 presents the variables that have been analysed in this work.

Table 6. Variables analysed in the evaluation of the UNAV

Indicators
Nº of researchers
Funding through research projects
Nº of works in the databases of Web of Science

Overall, the UNAV produced a total of 2,229 works that have received a total of 19,716 citations. Some 41% of their works have been published in journals in the first quartile. The economic resources identified come from the funding of 534 research projects classified into 5 typologies: Europeans (4%); International (1%); Internal (17%), and Regional (40%). It is assumed that the human resources for the period analysed had an annual mean of 764 full-time researchers, of which 485 were doctors and the rest pre-doctoral students.

Software
For the calculation of the response surfaces, a specific program was used, Modde v. 4, of the company Umetrics of Sweden (www.umetrics.com)

Results and interpretation of the results
For the calculation of the response surface of the system "University of Navarre" (UNAV), we used a CCF design with restriction, as shown in Figure 5. The cloud of points represents the group of

departments in the area of Health Sciences of UNAV. The points highlighted are those departments that have the characteristics closest to the CCF type of design with restrictions.

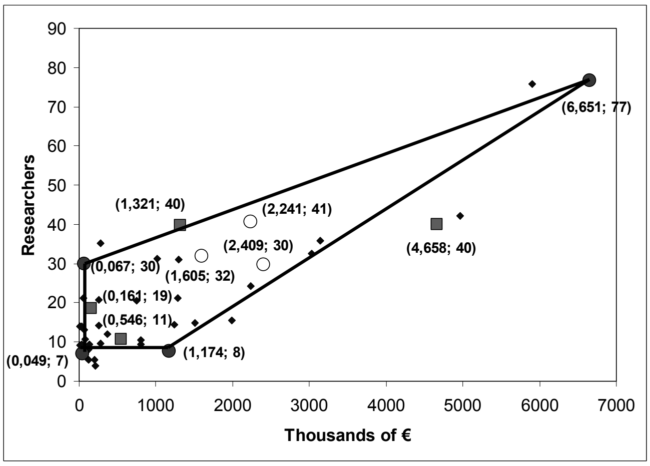

Figure 5. CCF design with restrictions for the UNAV system

The factors used are the number of researchers, S, and the funding, in the form of decimal logarithm, log F (F is expressed in thousands of €). The response is evaluated as production, P, of scientific articles listed in the Web of Science. The best fit corresponds to a linear response with respect to the number of researchers, while with respect to the logarithm of the funding the response is simultaneously linear and quadratic. There is also a response with respect to the interaction researchers-funding, which signifies that there is a synergetic effect between the two factors.

$$P = 233 - 2.6S - 191\log F + 44(\log F)^2 + 1.25S\log F \qquad R^2 = 0.865 \quad Q^2 = 0.722$$

The goodness of the response surface represented by Eq. 1 is acceptable (R^2 and Q^2 are well) On the other hand, the F test of Snedecor confirms also that the fit is satisfactory at the significance level of 5%.

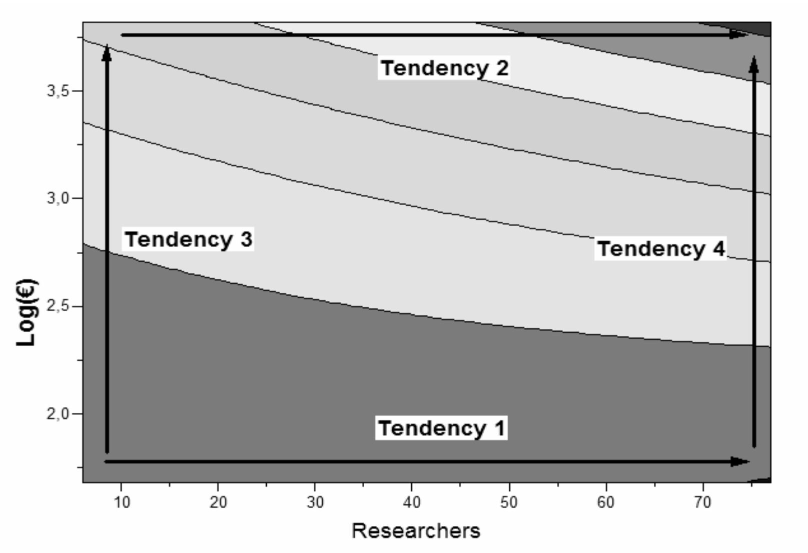

Figure 6. Flat or contour representation for the system UNAV

However, perhaps the most interesting aspect, from our viewpoint, is the generation of a graphic model that synthesises the weight of the variables chosen and their influence on the results as these variables are changed. There are two basic representations of the model: flat and contour (Figure 6), and three-dimensional or superficial (Figure 7).

From the flat and the three-dimensional representation, it is now very easy to explain the behaviour (response) of the scientific system of the UNAV according to whether the factors affecting the production of articles of the departments are affected or not.

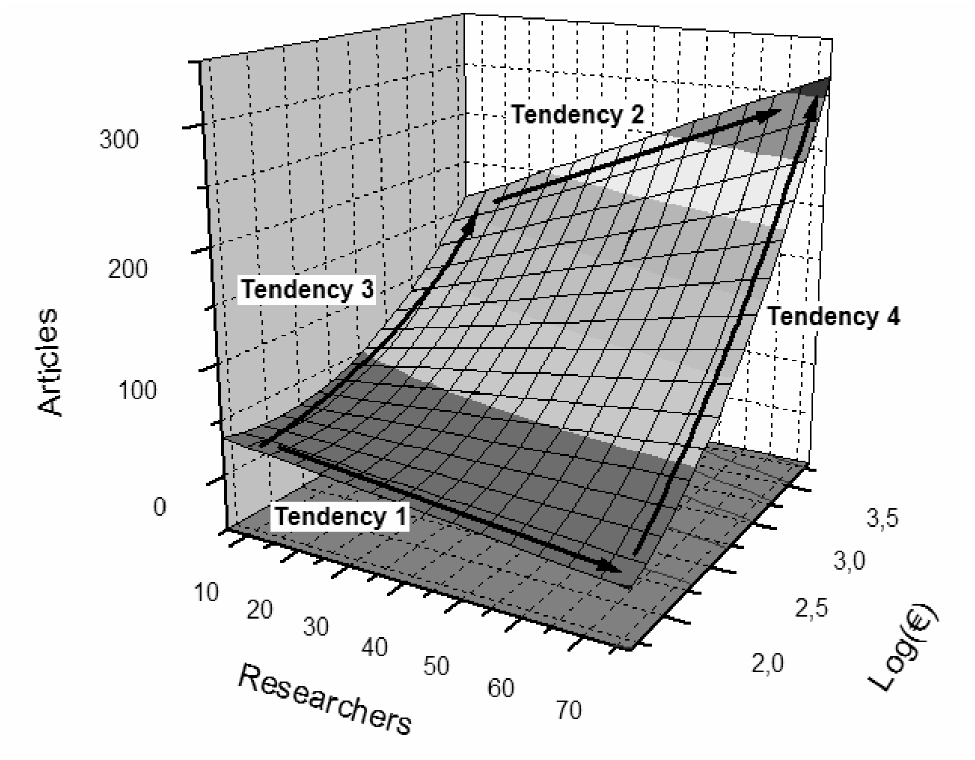

Figure 7. Three-dimensional representation of the surface of the system UNAV

Movement one (Tendency 1) shows what happens in the system when, under low funding, the number of researchers increases. Although it may proved unexpected, the result predicts a fall in scientific production. The explanation, however, proves attractive, when the resources are scarce, the increase in staff would prove counterproductive inasmuch as, with decreasing research funds as a consequence of the increase in researchers to attend, the capacity of producing new works tends to diminish (dark-blue fringe), as insinuated in the lower-right corner. Nevertheless, the capacity of the model in this sphere should not be exaggerated due to the scarcity of the data at this level, to their variability

Movement three (Tendency 3) shows the evolution in the situation of increasing funding with comparatively lower increases in staff. The possible situations covered by the blue and green segments show a progression in the results that even triple those obtained with low funding. Finally, great increases of investment are accompanied by a greater exponentially greater response, especially in the final part of the graph.

Finally, *movements two and four* (*Tendency 2 and 4*), which begin with few researchers having abundant financing and many researchers with little funding, the two groups converging in the form of many researchers with much funding. This inevitably marks a similar trajectory that culminates at the maximum limit of the results found in the case of the UNAV. However, the trajectories are not identical; in the first case the path is longer, given that it begins from a more deficient situation. In this sense, the general topography of the sample surface shows that it is far more effective to have fewer human resources with better funding, than the contrary case. In other words, the economic variable is determinant in the human.

Conclusion

Although we know that the impact factor (IF) of a journal does not predict the IF of an author or a particular work, what seems evident is that the prestige itself of the journal attracts citations in that we group only a certain number of works. The authors that publish in high-impact journals, which have more capacity to select from among the many works sent to them, are more visible to the scientific community, this constitutes the other determining element and closes the *virtuous* circuit of research with impact.

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