QUALITY AND RELIABILITY ENGINEERING INTERNATIONAL
Qual. Reliab. Engng. Int. (2009)
Published online in Wiley InterScience (www.interscience.wiley.com). DOI: 10.1002/qre.1016

Research

The Hirsch Index in Manufacturing and Quality Engineering

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The Hirsch index (h) is a recent bibliometric indicator for assessing the research output of scientists. Its most remarkable characteristics are immediate intuitive meaning, effective synthesis and easy calculation. With few modifications, the use of this indicator can be profitably extended to other fields beyond bibliometrics. The main novelty of the paper is to suggest some potential applications in manufacturing and Quality engineering, focussing the attention on the h capacity to aggregate and synthesize the most commonly used metrics in these areas. Copyright © 2009 John Wiley & Sons, Ltd.

KEY WORDS: Hirsch index; synthesis indicator; performance evaluation; manufacturing; Quality engineering

1. ORIGIN OF THE h INDEX

The Hirsch index (h) is a recent bibliometric indicator for evaluating and comparing the activity of individual scientists according to their scientific publications. h is defined as the number such that, for a general group of papers, h papers received at least h citations while the other papers received no more than h citations[1]. For the example in Figure 1, we can say that the author is $h=7$. In this way, h synthetically aggregates two important aspects of the scientific output: diffusion/impact, represented by the number of citations per paper, and productivity, represented by the number of different papers. Moreover, growing both with the publications number and the citations number, h encourages the production of good scientific works.

Ever since its introduction, this indicator has received much attention. This is not only the effect of the increasing attention towards the problem of evaluating the scientists' output, but—most of all—it is due to the natural simplicity, the immediate intuitive meaning and the apparent effectiveness of h[2,3]. In fact, h is directly associated with real data (the number of publications and citations), and does not require any conversion, scale transformation or data processing[4–6].

The original aggregation criterion of h is based on the fact that the two examined quantities (publications and citations) are generally represented by numbers with the same order of magnitude. Furthermore, h can be calculated very quickly using input data, which are available in specialized databases, such as the Web

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citations for each paper	rank
30	1
20	2
18	3
12	4
9	5
8	6
8	**7**
6	8
6	9
5	10
…	…

h=7

Figure 1. Example of h-index calculation. In this case $h=7$, since seven papers received at least seven citations each

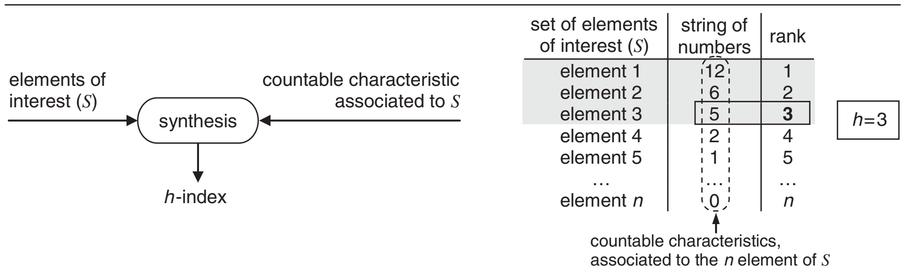

Figure 2. General interpretation of the h-index. The indicator is applied to a generic string of (n) numbers associated with a set of elements (S), in order to synthesize them into a single number

of Science or Google Scholar. A survey of the h-index's most important operational properties and peculiar scale properties can be found in[7,8].

2. EXTENSION TO OTHER APPLICATION FIELDS

This paper attempts to extend the h-index to manufacturing and Quality engineering. Is it reasonable to say: 'In this work shift, the production Quality has improved because the $h$value has decreased by one point', or 'In the previous two years, the sales of the product X were, respectively, '$h=6$' and '$h=8$'? The answer is apparently not. However, this paper will show that these statements can make sense.

To investigate this possibility, a wide-ranging interpretation of the indicator should be briefly provided. In general, h can be seen as an indicator able to aggregate the information related to two observable quantities:

- a set (S) of n elements of interest (in the h-index's original definition, the different publications of a scientist);
- a countable characteristic associated with each element of S (in the h-index's original definition, the citation rate of the different publications).

This information is organized in a string of n natural numbers, representing the values of the countable characteristic related to the elements of S, sorted in descending order (see Figure 2).

Determining the h value does not require complex calculation. With reference to the example in Figure 2, $h=3$. h provides an immediate 'snapshot' of the most important elements of S, according to the countable characteristic investigated. This is not so common among indicators. It is worth reminding that an indicator

DOI: 10.1002/qre

Table I. Information required to calculate the h-index for the (classical) application in bibliometrics

Application: Bibliometrics		Specific information
Goal		Evaluation of the scientific output of a scientist
Observable quantities	1. A set (S) of elements of interest	Number of publications of a scientist
	2. A (countable) characteristic feature associated with each of the S elements	Number of citations of each paper
Source of the input data		Specialized and public databases (i.e. Web of Science and Google Scholar)

is successful not only if it is effective, but also if it is easily understood. Indicators for which reference to real data has been 'lost' are difficult to understand and interpret, and often rejected by potential users[9]. For this potential benefit, the use of the h-index could be effectively extended to other application fields. Table I summarizes the h-index's input information in its classical use.

In the remainder of this paper we show some of the potential applications in manufacturing and Quality engineering. Description is supported by several explanatory examples.

3. APPLICATIONS IN MANUFACTURING AND QUALITY ENGINEERING

In the following subsections we exemplify five possible applications of the h-index. They are, respectively:

3.1. evaluation of a production's defectiveness (Quality control);
3.2. evaluation of the sales of products with multiple model-ranges;
3.3. Quality evaluation of the lots received from suppliers (acceptance sampling);
3.4. evaluation of the inventory efficiency;
3.5. synthesis of the information contained into a Pareto chart.

3.1. Production Quality control

Let us consider a manufacturing process for the production of car exterior body panels. For keeping high Quality levels, the parts are directly controlled in the press shop with a manual procedure. At the end of the press line, an experienced worker checks all the produced parts by treating their exterior surfaces with a grindstone. From the resulting specific patterns of local grinding marks he is able to detect form deviations, and derive their type and acceptance. Defects detected in every panel are noted down by workers. A list of the most common surface defects is reported in Table II[10].

The use of h can provide a synthetic indication of the product defectiveness. Table III illustrates the necessary data for this application. Let us assume that h is calculated for each individual work shift. For instance, at the end of a work shift, the process is said to be '$h=4$' if four defective parts contain at least four defects each, while the other defective parts contain no more than four defects.

From the point of view of the process Quality, since both the observable quantities in Table III (defective units produced and defects per unit) have a negative connotation, the h value has to be reduced as much as possible in order to improve the process. It is important to notice that the h-index is able to summarize the performance of a process in a single number. This synthesis can be particularly useful for evaluating the performance of critical processes, such as the final testing of complex products (i.e. cars, aircrafts, etc.). As further applications, h could be used:

- to evaluate the performance of a process over time (e.g. work-shift by work-shift);
- to compare concurrent production lines manufacturing the same product (see Figure 3).

DOI: 10.1002/qre

Table II. List of possible surface defects with respect to car exterior body panels[10]

Defect type	Description
1. Uneven surface	Several sink marks in series or adjoined
2. Press mark	Local smoothing of surface, heavier sink mark, deep depression preceded by a low peak
3. Dent	Rounded damage inward, distinctive feature
4. Bulge	Rounded damage outward, distinctive feature, relatively small radius
5. Sink	Mark slight flat based depression inward
6. Flat area	Flat plane on curved cumber surface
7. Uneven radius	Visible distortion of radius geometry

Table III. Information used by the h-index in a Quality control application

Application: Production Quality control		Specific information
Goal		Evaluation of a process' defectiveness
Observable quantities	1. A set (S) of elements of interest	Number of produced parts
	2. A (countable) characteristic feature associated with each of the S elements	Number of defects found in every defective unit
Source of the input data		Results of the Quality control activity related to an individual work shift

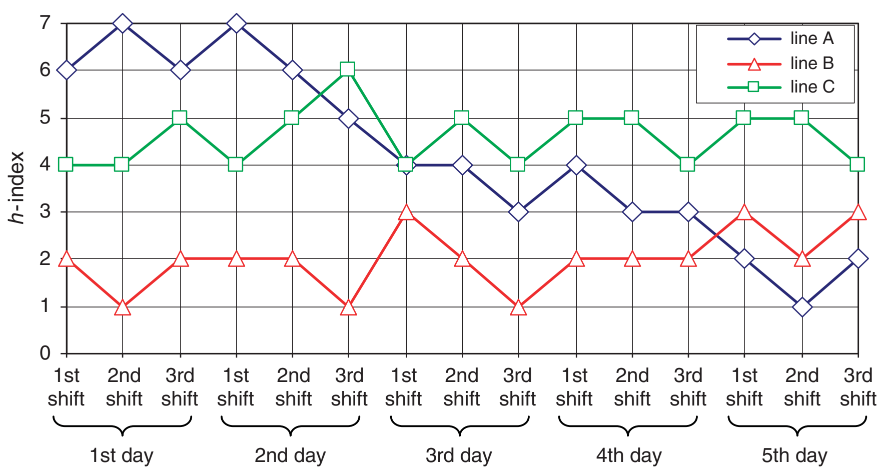

Figure 3. Use of the h-index to evaluate a process' defectiveness over time and compare concurrent production lines. This figure is available in colour online at www.interscience.wiley.com/journal/qre

In common practice, process defectiveness is evaluated considering the number of defective products or the number of defects separately. The typical tools for this kind of analysis are control charts for defectives and control charts for defects, respectively. Using the h-index, it is possible to aggregate these quantities (i.e. defectives and defects) into a single indicator. For example, we could monitor a complex process by means of a control chart based on the h-index (see Figure 4). Of course, the definition of the chart control limits should be derived from a statistically sound reasoning[9].

3.2. *Sales of products with multiple model-ranges*

h can be used to synthetically represent the sales of a product with multiple model-ranges. In this specific application, h takes into account both the product's model-ranges and the number of units sold for each of them (see Table IV).

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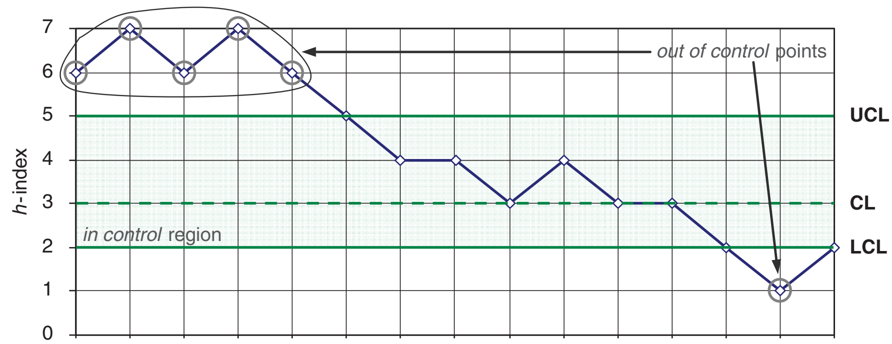


Figure 4. Example of a control chart based on the h-index. This figure is available in colour online at www.interscience.wiley.com/journal/qre

Table IV. Information used by the h-index for representing the sales of a product with multiple model ranges

Application: Sales of a product with multiple model-ranges		Specific information
Goal		Evaluation of the sales of a product with multiple model-ranges
Observable quantities	1. A set (S) of elements of interest	Number of product model-ranges
	2. A (countable) characteristic feature associated to each of the S elements	Number of units sold for each model-range
Source of the input data		Databases of the product sales

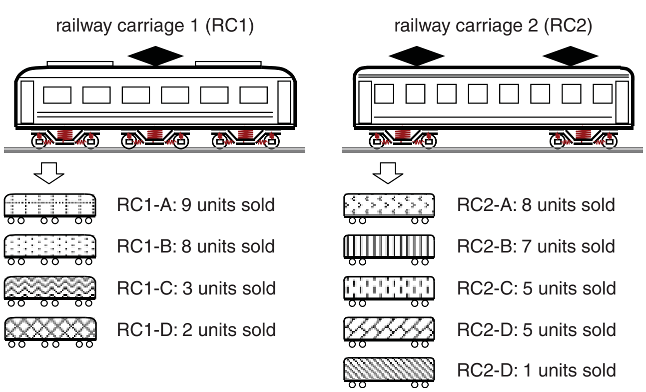


Figure 5. Representation of the yearly sales of two railway carriages with multiple model-ranges each. This figure is available in colour online at www.interscience.wiley.com/journal/qre

For the purpose of example, Figure 5 represents the yearly sales of two families of railway carriages, with 4 and 5 multiple model-ranges, respectively.

The corresponding h-index calculation is reported in Figure 6. In this case, the h value of railway carriage 1 is smaller than the h-index of railway carriage 2. They are 3 and 4, respectively.

As noticed before, in this application h considers two features of a product:

1. the number of versions (assessment of the product diversification);
2. the number of units sold for each model-range (assessment of market penetration).

These two features are aggregated for finding the number h such that h model-ranges correspond to at least h units sold. According to this evaluation, products with a large number of model-ranges that are uniformly

DOI: 10.1002/qre

well sold have large h values. This is reasonable for a market in which not only the amount of product sold but also the product diversification has a growing importance.

3.3. *Acceptance sampling*

In a company receiving lots of components from a supplier, acceptance sampling plans are implemented. Lots are accepted or rejected depending on the number of defective parts found in samples, which are selected from the lots. Then, 100% of the rejected lots are screened by the supplier in order to find the total number of defectives. Assuming that a rectifying inspection program is adopted, all discovered defective items are either removed for subsequent rework or replaced from a stock of good items. Of course, rejected lots represent additional costs for the supplier and for the company itself (due to the consequent supply delay). The total number of defective parts is an indicator of the supplied lot Quality.

h can be introduced in the acceptance sampling for evaluating the quality of lots, for a well-defined reference period. Specifically, h can be used to aggregate two quantities of interest: the total number of daily rejected lots and the number of defective parts in each rejected lot, as illustrated in Table V.

For example, a reference period is classified $h=5$ when it includes five rejected lots with at least five defects each (see the example in Figure 7).

As both the previous observable quantities have a negative connotation from the point of view of the supplied lot Quality, the supplier's effort has to be focussed on reducing h as much as possible. At the

Railway Carriage 1 (h=3)

model-range id	units sold	rank
A	9	1
B	8	2
C	3	**3**
D	2	4

Railway Carriage 2 (h=4)

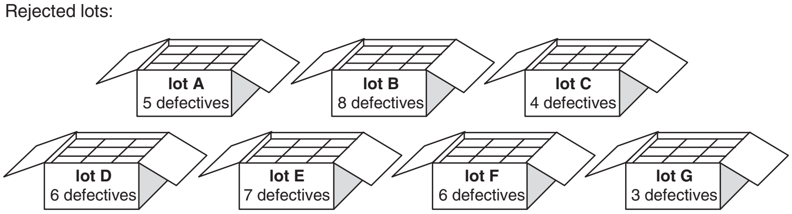
model-range id	units sold	rank
A	8	1
B	7	2
C	5	3
D	5	4
E	1	5

Figure 6. Calculation of the h-index for two products (railway carriages) with multiple model-ranges each

Table V. Information used by the h-index to evaluate the Quality of the lots received from a supplier

Application: Acceptance sampling		Specific information
Goal		Evaluation of the Quality related to lots of components received from a supplier
Observable quantities	1. A set (S) of elements of interest	Number of lots rejected
	2. A (countable) characteristic feature associated to each of the S elements	Number of defective units for each rejected lot
Source of the input data		Results of the acceptance sampling

Rejected lots:



Input data table (h=5)

rejected lots	no. of defects	rank
lot B	8	1
lot E	7	2
lot D	6	3
lot F	6	4
lot A	5	**5**
lot C	4	6
lot G	3	7

Figure 7. Use of the h-index to evaluate the Quality of supplied lots, based on the number of defective elements in each rejected lot

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same time, h can be used to monitor the evolution of the supplier's Quality over time or to compare the performance of different suppliers.

3.4. *Inventory efficiency*

Let us consider the end-product inventory of a company adopting a *pull* production system, i.e. driven by the real customer's demand. In this situation, it is necessary to coordinate the production according to the market demand, so as to:

- reduce the amount of stored end-products, waiting to be delivered (1st observable quantity);
- reduce the storage time of every end-product (2nd observable quantity).

In this way, the inventory cost and the risk of product obsolescence would decrease. The two previous observable quantities can be aggregated using h, as shown in Table VI

In a particular instant, for example, a warehouse is said to be $h=6$, if it contains six products that have been stored for at least 6 days each. Figure 8 illustrates a practical application: the h value is calculated at the end of each day, in order to provide a synthetic indication of the inventory efficiency.

It can be noticed that the two observable quantities considered are indicators of inventory inefficiency; therefore, the goal is to reduce h. This can be done by optimizing the production flow or coordinating the distribution network. Of course, an excessive reduction of h could increase the risk of product shortage (which is not taken into account by h).

Table VI. Information used by the h-index for representing the efficiency of an (end-product) inventory

Application: Inventory efficiency evaluation		Specific information
Goal		Evaluation of the inventory efficiency
Observable quantities	1. A set (S) of elements of interest	Number of stored products
	2. A (countable) characteristic feature associated with each of the S elements	Storage time related to each product (expressed in days)
Source of the input data		Inventory control database

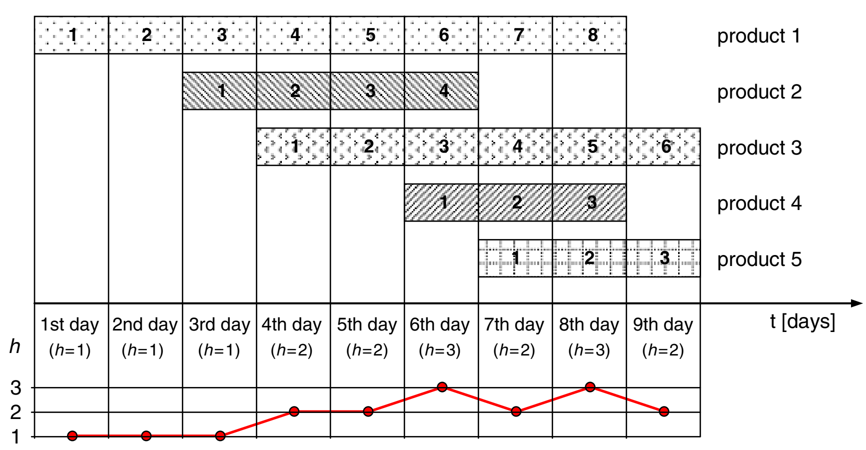
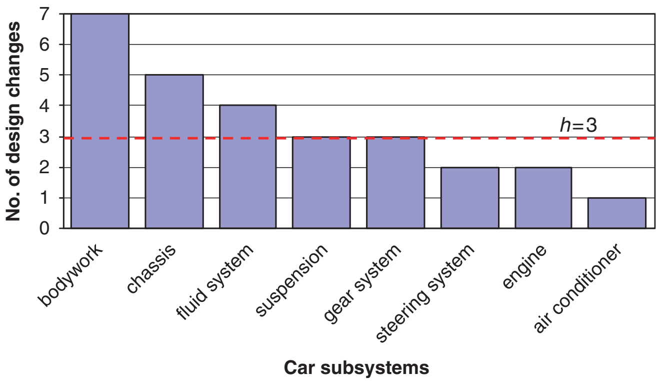


Figure 8. Use of the h-index as a synthetic indicator for the evaluation of the inventory efficiency. In this example, h is calculated at the end of each day, considering the stored products and the corresponding storage times expressed in days. For example, at the end of the 6th day, $h=3$ because there are three products that have been stored for at least 3 days each (i.e. products 1, 2 and 3, with 6, 4 and 3 days of storage, respectively), while the remaining one (product 4) has been stored for 1 day only. This figure is available in colour online at www.interscience.wiley.com/journal/qre

DOI: 10.1002/qre



Input data table (h=3)

car subsystems	no. of changes	rank
bodywork	7	1
chassis	5	2
fluid system	4	**3**
suspension	3	4
gear system	3	5
steering system	2	6
engine	2	7
air conditioner	1	8

Figure 9. Pareto chart representing the number of design changes associated to the major subsystems of a car. Specifically, changes made in the last 6 months before the product's introduction into the market are considered[11]. This figure is available in colour online at www.interscience.wiley.com/journal/qre

Table VII. Information used by the h-index for synthesizing the information contained into a Pareto chart

Application: Synthesis of a Pareto chart		Specific information
Goal		Synthesizing the information contained into a Pareto chart
Observable quantities	1. A set (S) of elements of interest	Items/events (e.g. the different subsystems of a car)
	2. A (countable) characteristic feature associated with each of the S elements	Quantity/frequency of occurrence of one characteristic feature related to the items/events (e.g. the number of design changes)
Source of the input data		Database of the product development activity

3.5. *Pareto chart*

Typically, Pareto charts are used to represent some items/events of interest sorted in descending order depending on the quantity/frequency of occurrence of a countable characteristic feature (see Figure 9). For synthesizing the information contained into this kind of diagram, h can be defined as shown in Table VII.

Let us consider, for example, the subsystems of a car (bodywork, suspension, engine, etc.). As it is known, the corresponding number of design changes and their costs in the last stage of the product development cycle becomes higher and higher[11]. Figure 9 shows the Pareto chart related to changes made in the last 6 months before production.

In order to reduce the product development time/cost and increase the efficiency of the manufacturing process, h should be minimized. It is interesting to notice that the h-index is able to summarize the information of the Pareto chart into a single number (in our example $h=3$). This synthesis can be very effective to make quick comparisons between different Pareto charts. Otherwise, this task is not so immediate and practical. With reference to the previous example, the Pareto charts associated with different car models can be easily compared using the corresponding h values.

4. *CONCLUSIONS*

This paper shows some of the many potential applications of the h-index. Even though h is originally derived from bibliometrics, it could be profitably used for different specific problems in manufacturing and

DOI: 10.1002/qre

Quality engineering, so as to synthesize and enrich the most commonly used metrics. In particular, we suggest possible applications in production Quality control and acceptance sampling, for the evaluation of the product sales, the inventory efficiency and to synthesize a generic Pareto chart. The great advantage of h is to aggregate the information related to two observable quantities into a single number, without losing the reference to real data. Moreover, the calculation of the indicator is immediate and based on input data that are generally available. These characteristics could be decisive in facilitating the use of h for applications in manufacturing and Quality engineering.

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Domenico A. Maisano graduated cum laude in Mechanical engineering, from Politecnico di Torino, where he is currently Assistant Professor. From 2003 to 2005, he was involved in a project in the area of Quality Management for FIAT Auto. In 2008 he received his PhD degree in Systems for the Industrial Production from Politecnico di Torino. His current research interests are industrial large-scale metrology and Quality management. He is the co-author of 2 books and 15 publications on international journals and proceedings.

DOI: 10.1002/qre