# WORKING PAPER

COMPANY SIZE, AGE AND INNOVATION ACTIVITY
IN THE STEEL INDUSTRY
(Example of BOF Technology)

Milan Maly

April 1987
WP-87-036

IIASA
International Institute
for Applied Systems Analysis

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## FORWARD

In an era of technology globalization, management appears to be one of the main factors influencing success in technological development. The flexibility and speed with which a company or country is able to identify and introduce new technologies appear to be the most important factors for its subsequent success. Today possibly more than ever, the characteristics of management and organization which enable a company to be innovative are claiming the attention of managers and politicians. No less important is a company's or country's flexibility in exploring and developing already-introduced technologies.

The possibility of describing the process of technology substitution through logistic functions is one method of forecasting future development of a technological species and one which is not yet fully utilized in practice. The management implications of the life cycle concept appear to be very important for managerial practice, but this is a tool which has not yet been fully adapted to managerial needs.

The study and analysis of management dynamics along the different phases of the life cycle can make possible the definition of different management applications of the life cycle concept. Based on this, useful conclusions can be drawn for decision-makers.

Size is one possible characteristic to describe organizational status and management, and the dynamics of size during different phases of the life cycle can indicate the innovative capabilities of small-, medium- and large-scale industries. This is the main objective of the study presented, which in constrast to prior studies, concentrates on two new aspects: new methods of clustering firms and, based on this, analysis of the role of firm size and age in different phases of the life cycle of BOF technology.

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MTL Principal Investigator

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# 1. INTRODUCTION

In 1986, a new program called "Technology, Economy, Society" was launched at IIASA. This very ambitious program consists of several projects and activities. One of these is "Management and the Technological Life Cycle" (MTL), whose main objectives are to determine the possibilities of long-term management planning, organizational changes, and increased organizational flexibility which will facilitate the introduction and development of new technologies.

The first field of MTL's research is the steel industry, and the concrete topic of basic oxygen technology (BOF) was selected as an example of the latest major innovation in steel manufacturing.

A few studies have been carried out previously in this area. For example, Lynn (1982) studied the problem as a comparison between the way Japan and the U.S. adopted BOF. Buzacott (1980) carried out a study regarding the adoption of BOF at Canadian steel companies. Martino (1978) described the diffusion history of BOF in the USA, and Meyer and Herregat (1974) conducted a detailed study of the diffusion of the basic oxygen process on a global scale, reaching two main conclusions. First, they found that most of the differences between firms, and perhaps to an even greater extent between national industries, could be explained by objective differences in the economic environment in which these firms or industries operate. Secondly, they also determined that some of the differences observed between firms or national industries are attributable to such non-economic factors as differences in management styles and motivation.

Ray (1984) studied the diffusion of BOF mainly during the period between 1969-1981, and stated that BOF approached maturity in the late 1960's and has now practically displaced all other technologies with the exception of electric steelmaking.

Rosegger (1980) analysed the reasons for the delayed introduction of BOF into U.S. companies.

Poznanski (1986) analyzed the process involved in the decline of technologies in the world's steel industry and investigated the basic patterns through which the technologies are phased out once they become obsolete.

Part of this MTL activity has involved analyzing the role of company size and age as important organizational attributes in the area of strategic management, especially innovation management. The main objective of our current study is to specify the role of company size as a factor of time, where time is represented by the phases of the technological life cycle. The new elements in this study are the global worldwide viewpoint and the usage of the technological life cycle concept. Moreover, a new methodological access for dividing companies into groups has been developed. The study, being an inherent part of the MTL activity, is based on that activity's data base and some of its empirical and theoretical findings.

## 2. STATE-OF-THE-ART

There is a general impression among the public that small, young companies are more innovative than larger, older ones. The number of researchers studying the relationship between company size and innovation ability is very high.[1]

The notion that small, young companies are more innovative is far from unambiguous, but many authors are in agreement on the subject.[2] According to Bracker and Pearson, the entrepreneurial spirit housed in its small firms is perhaps the greatest advantage the U.S. has in the highly competitive world marketplace, while entrepreneurs are rarely found in large, mature industries. Schollhammer and Kuriloff (1979) are of the same opinion when they say that the natural habitat of entrepreneurs is small business. Siropolis (1977) states that small firms innovate while others are content to sit on their hands. Granstrand (1982) mentions that large and/or old industrial organizations are commonly thought of as hampering creative and innovative work.

But not only Western specialists stress that small, young firms are more innovative. Many researchers from Eastern countries agree.[3] One of the main features of the most recent Hungarian economic reform is the idea of increasing the number of small enterprises and companies in the Hungarian national economy.[4]

On the other hand, many authors[5] cite examples where large companies seem more innovative.

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[1]Freeman (1971), Johnnisson/Lindström (1971), Gold (1981), Scherer (1965), Smyth (1972), DeWoot (1977/78), Wilson (1966), Kuhn (1985), Sounder (1983), Buzacott (1980), Kleine (1980), Stroetmann (1979), Rothwell/Zegveld (1982), Nyström/Edvardsson (1978), Acs/Audretsch (1986), etc.

[2]Siropolis (1977), Bracker/Pearson (1986), Schollhammer/Kuriloff (1979), Rothwell/Zegveld (1982), Freeman (1971), Nyström/Edvardsson (1978).

[3]Tragsdorf, 1985; Remes, 1984; etc.

[4]Csath, 1986.

[5]Baark/Anxian (1985), Patrick/Rosovsky (1976), Maitland (1982), Kleine (1980).

Baark and Anxian (1985) mention the example of Swedish engineering companies, the diffusion of NC, IR and CAD/CAM. As a comparison of the different diffusion patterns of CIM shows, the more advanced the technology and the more factors involved, the more difficult the diffusion. Many companies, especially small and medium-sized ones, lack both the financial and technical base for adopting such technology in its early stages. The role of large companies depends to a great extent on their ability to realize that technical and commercial success requires more than simply producing high-quality machines and components. It is vital to combine them and adapt them to each other, thereby forming complete equipment systems and satisfying customers' needs. Because of this, many large Swedish engineering companies have decided to develop a very wide range of technically superior products, in an effort to develop a high level of engineering know-how in a great variety of fields.

Patrick and Rosovsky (1976) feel that the agents of Japan's rapid advances in technical knowledge and its remarkable economic growth have been the country's larger firms. Maitland (1982) comes to more or less the same conclusion: that large Japanese enterprises have an astonishing record of innovation.

Kleine (1980) analyzes innovation activity through the number of patents owned in companies of different sizes and concludes that medium and large companies are more innovative as compared with smaller ones.

This view is supported by the hypothesis of Kamien and Schwarz (1982) that large firms tend to be proportionally more innovative than small firms.

A further third group of researchers[6] feel the problem of determining which size of firm (small, medium or large) is most innovative is much more difficult to resolve.

Ayres (1986) finds it fairly clear that the simple inversive relationship between innovation and firm size is not generally true. Wilson (1966) proposed a partial theory about the relationship between organizational structure and innovation, the hypothesis being that the effects of greater organizational diversity are contradictory, stimulating an organization's capacity to generate innovative proposals while inhibiting the capacity to adopt and implement them. Wilson concludes that this may explain why the evidence on this issue is inconclusive.

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[6]Ayres (1986); Wilson (1966), Acs/Audretsch (1986), Maly/-Zaruba (1986), Smrcka (1985).

Acs & Audretsch (1986) analyzed innovation rates at large and small firms for 247 four-digit SIC industries and came to the conclusion that innovation activity for large firms responds to a different market environment than innovation activity for small firms.

After studying the diffusion of mature technologies, Ray (1984) came to the conclusion that size has less to do with the diffusion of new technologies in the mature phase than was believed some 10 or 20 years ago.

At the workshop, "Size and Productive Efficiency: The Wider Implications," held at IIASA in June, 1979, one of the major topics of discussion was the relationship between scale and innovation, in particular the way in which the development and adoption of innovations are influenced by the size of the firm. One result was that an optimum organization size exists for major process innovations: not so small that a diversity of managerial experience is lacking and not so large that there is rigid bureaucracy and lack of common purpose.

This review of state-of-the-art research on the issue demonstrates a wide diversity of opinion among researchers. We hypothesize that the optimal company size from the point of view of innovative activity depends on many factors (industry, technological life cycle phase, country size, country's industrial structure, etc.) and changes according to these factors. From this viewpoint, we cannot speak of an optimal size in general, but only of an optimal size under specified conditions. We must consider the fact that the optimal size is changing over time in conjunction with the changing critical factors.

## 3. METHODOLOGY

Solving the objectives outlined above involves a number of methodological issues. The first problem is how to specify company size. A great number of authors are looking into the problem of company size and scale,[7] mainly from the point of view of the relationship between company size and economies of scale.

Despite the large number of studies, a conceptual definition regarding size and scale had been lacking for a long time. In 1981, Gold defined scale "as the level of planned production capacity which determines the extent to which specialization has been applied to the subdivision of the component tasks and faci-

[7]Aldrich (1962), Blau (1962), Bolotnyi (1976), Buzacott/Cantley/Glagolev (1982), Gold (1981), Kimberley (1976), Miller (1978), Morodney (1969), Pugh/Hickson (1963), Silberston (1972), Stigler (1976).

lities of a unified operation." This definition makes it possible to differentiate between scale and size. Size refers to designed capacity and scale to planned production capacity, which can be increased for instance by utilizing higher levels of specialization.

Company (or enterprise or other organizational unit) size is measured by many different criteria, as one comprehensive criterion to specify size has not yet been agreed upon. These criteria can be divided into 3 main groups:

* company's material substance,
* company input,
* company output.

Material substance measurements would usually include the number of employees, the value of capital goods, and total capital. Input is expressed mainly by the consumption of raw materials or energy, and output by number of units/tons produced, gross output, etc.

Using any one of these criteria has both strong and weak aspects. For example, the most wide-spread criterion is probably the number of employees, but difficulties arise with this in the case of automated production. Each criterion conveys different aspects of size. From that point of view, it is necessary when conducting a concrete analysis to select the criterion most appropriate for fulfilling the objectives of the analysis, in an effort to eliminate inconclusive results.

The object of our study is the steel industry, namely BOF technology. The most significant and comparable criterion in this case is **the capacity of raw steel production per year.** This criterion is usually used to indicate the size not only of a steel-mill plant, but of the entire integrated steel company as well. Moreover, the criterion is widely used in literature, statistics and reports as well as in articles and research papers. It is furthermore used in both planned and market economy countries.

Using the number of company employees is not acceptable, because of differences in production profiles, mainly of the rolling-mills, which greatly influence productivity and the required number of employees involved. Other material substance criteria, such as the value of capital goods or total capital, could be used, but are less suitable when taking into account not only Western, but also Eastern companies (where this data is not available). Input criteria, such as consumption of raw materials or energy, are also not available in many cases. Output criteria, for instance total volume of raw steel production per year, is influenced by the level of capacity utilization.

The second methodological issue is specifying the boundaries between groups of company size. Three groups are usually distinguished in literature, official statistics and reports as small, medium and large companies.[8] Authors, however, use different boundaries for the three groups. These boundaries depend on the object of the study under question: an entire industry, different branches of industry, or other branches of national economies (agriculture, transport, service, etc.). For instance, Nyström & Edvardsson use the following boundaries for the farm machinery industry: small up to 9, medium between 10-50, and large over 50 employees. Hungarian industrial statistics use up to 1500 employees for small, from 1501 to 4000 for medium, and over 4000 for large.

Statistics covering the steel industry usually use the following divisions: up to 500,000 tons of raw steel capacity per year for small companies, 500,000 to 1,500,000 tons for medium, and over 1,500,000 tons for large. This division is also used in literature.[9] If we examine this more deeply, we must state that so far these boundaries have been established most subjectively and are hardly suitable for a detailed analysis. Our idea is to create more natural and homogeneous groups by means of suitable mathematical methods, in order to derive more statistically significant results. Figure 1 shows us the example of Swedish steel companies divided by the customary boundaries. At once, it is clearly visible that these boundaries do not create any natural, homogeneous groups.

SWEDEN - SIZE OF STEEL COMPANY - CRUDE STEEL OUTPUT

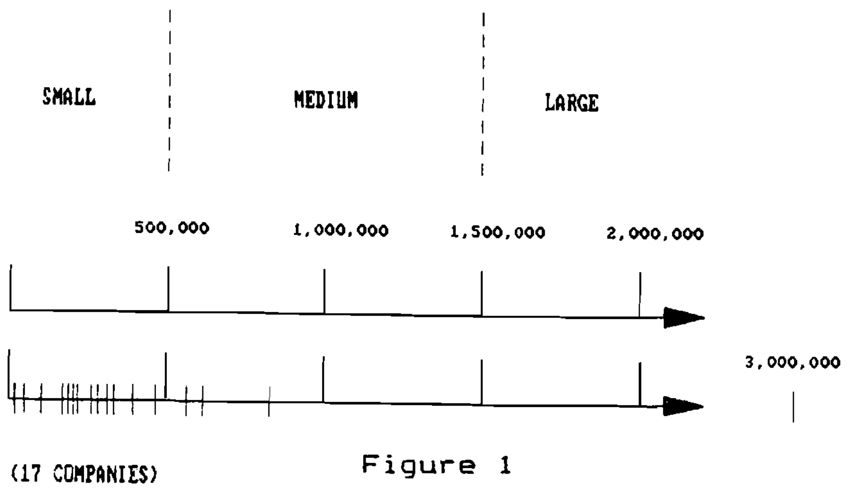


Figure 1

[8]Nyström/Edvardsson (1978), Nabseth/Ray (1974), Tragsdorf (1985), Smrcka (1985), Remes (1984).

[9]Nabseth & Ray, 1974.

In our case, we used a new method for clustering points located on the line of real numbers, combining cluster analysis and histogram as developed by S. Miyamoto (see Attachment 1). The method was not fully applied; it served only as a scientific framework for specifying the boundaries.

After clustering the companies into more homogeneous groups, we come to the very difficult methodological problem of how to distinguish the more innovative companies from the others. We are aware of the difficulties this task presents, but it is possible, however, to formulate the hypothesis that the more innovative companies are those who **adopted a new technology or product in the early period following its first adoption globally.** The next methodological question arises immediately: how to specify the "early period following its first adoption globally."

To answer this question, we start from the premise that specifying such a period is possible by means of the theory of the technological life cycle. This particular theory has been developed mainly by Abernathy and Utterback (1975). Empirical evidence demonstrate that product and process technologies show a rather predictable pattern of dynamic behavior.[10]

The typical S-shaped function is designed usually by means of the degree of penetration of technology as measured by market share, percentage of adoption, etc., expressed usually by annual capacity or output. We suggest designing the S-shaped curve by means of the share of the BOF early adopters to the total number of integrated steel companies in the world. This is because we want to recognize the early adopters, the firms which adopted BOF during the early (i.e. take-off) phase of the technological life cycle. We try to eliminate the cases when these same firms adopted BOF later on at other plants.

For calculation, we used the simple Fisher and Pry model:[11]

**Equation 1.**

$$\ln \frac{f(t)}{1 - f(t)} = c + bt$$

The curve is symmetrical, $b(t) = b = $ constant, and point of inflection $f*(t) = 0.5$; $f(t)$ is the share of the early adopters of BOF to the total number of inegrated steel companies worldwide and c, b are the parameters defining the S-shape.

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[10]Ford/Ryan (1982), Pappas (1984), DeBresson & Lampel (1985).

[11]Fisher/Pry (1971).

So far, we have not developed a exact method to help us define the boundaries between the consecutive phases of the technological life cycle. The literature regarding this particular problem is not very helpful.[12] The only possibility at the moment is to specify the boundaries from some technological and economic indicators. The take-off phase measures the period during which the early adopters started to produce steel using BOF technology.

The last, but perhaps the most important, issue is to what extent do we require a data base to resolve the issues. We must take into account not only our specific task, but also the availability of data. Because the steel industry is well documented in statistics and literature, we have decided to gather information from many countries around the world, bearing in mind that not all steel companies can adopt BOF. BOF technology can be adopted only by companies with certain technological prerequisites. This implies that we must restrict our attention to integrated steel plants (i.e., those with blast furnaces, steel mills, and rolling mills), and moreover exclude those integrated steel plants producing only special grades of steel. In these instances, only electric furnaces, not open hearth or BOF, would be preferred.

The next question to arise is what year to take as a basis for the analysis of quantitative data. We suggested taking the year of BOF's first commercial adoption as the basis for our analysis.

To analyze the relationship between the age of a company and its innovativeness, it is not logical to use the same access (cluster analysis combined with histogram), because age is not dependent on a clustering of companies by age. Age must be taken as an independent factor. The only possibility is to divide time into regular periods and compare company results during these periods.

## 4. FINDINGS

The first commercial adoption of BOF technology was in 1952, when the first convertor came into operation at Voest, in Austria. From that point on, other steel companies had to include the option of adopting BOF into their strategic planning.

The main source for our data base is Cordero's survey of Iron and Steel Works of the World for 1952. This book includes all major producers of iron, raw steel and rolled steel products as well as many other producers of re-rollers, tubes, iron powder, etc. Hundreds of companies were analyzed from this book in order to select the integrated steel companies, excluding those concentrating their production exclusively on special grades of steel.

[12] There are only a few hints on this topic in Ford & Ryan (1982), Cleland & King (1983), and Meffert (1980).

The list of 74 companies (see Attachment 2) does not include all integrated steel companies worldwide, not only because of the traditional secrecy of the planned economy countries, but also because of secrecy policies in such countries as the United Kingdom, and others, for which data was not available. By our estimation, about 100-120 integrated companies existed in the world in 1952, so our sample contains more than 60% of the total.

We shall start our analysis using the standard classification of company size, i.e. up to 500,000 tons raw steel capacity per year for small; 500,000 to 1,500,000 for medium; and over 1,500,000 for large. Using these standard classifications, we obtain a division of integrated companies into groups shown in Table 1.

**Table 1**

| | Small | Medium | Large | Total |
|---|---|---|---|---|
| Number | 26 | 31 | 17 | 74 |
| Percentage | 35 | 42 | 23 | 100 |

The main sources for identifying the early adopters were Lynn (1982) and Stone (1966). The number of new firms adopting BOF worldwide by year from 1952-1970 is portrayed in Figure 2.

**NUMBER OF NEW FIRMS WORLDWIDE ADOPTING THE BOF BY YEAR, 1952 - 1970**

| YEAR | NUMBER OF FIRMS | CUMULATIVE NUMBER | YEAR | NUMBER OF FIRMS | CUMULATIVE NUMBER |
|---|---|---|---|---|---|
| | | | 1961 | 3 | 21 |
| 1952 | 1 | 1 | 1962 | 8 | 29 |
| 1953 | 1 | 2 | 1963 | 9 | 38 |
| 1954 | 2 | 4 | 1964 | 13 | 51 |
| 1955 | 0 | 4 | 1965 | 6 | 57 |
| 1956 | 0 | 4 | 1966 | 10 | 67 |
| 1957 | 5 | 10 | 1967 | 5 | 72 |
| 1958 | 5 | 14 | 1968 | 7 | 79 |
| 1959 | 1 | 15 | 1969 | 2 | 81 |
| 1960 | 3 | 18 | 1970 | 3 | 84 |

Source: L. Lynn (1982); J. K. Stone, (1966)

Figure 2

From that data base, the life cycle curve was created by means of the cumulative number of firms adopting BOF every year.

The estimated result of Equation 1 is as follows:

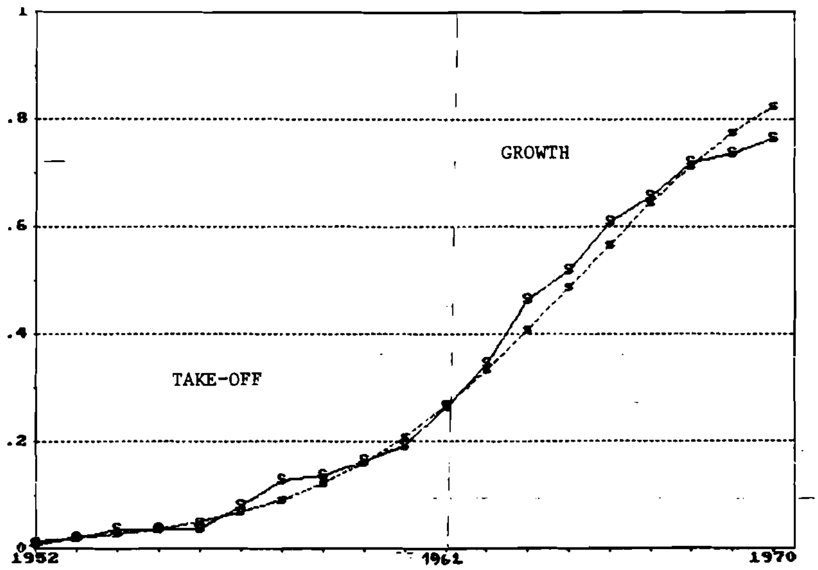
$$\ln \frac{f(t)}{1 - f(t)} = \underset{(32.7)}{.321} * (\text{year} - 1952) - \underset{(40.8)}{4.22}$$

$R^2 = .984$ $\qquad\qquad$ $\bar{R}^2 = .983$

D.W. = 1.06

where the values in the parenthesis are t-values.

Figure 3 shows the typical S-curve as a result of that sample, and Table 2 contains the actual value of the share of the early adopters to the total number of integrated firms and estimated value of that share.




Sources: L. Lynn (1982) & J.K. Stone (1966) (C) M. Maly, IIASA, 1987

Figure 3

Table 2

| YEAR | # OF EARLY ADOPTERS | f(t) | ESTIMATED f(t) | TOTAL INTEGRATED FIRMS |
|---|---|---|---|---|
| 1952 | 1 | 0.00909091 | 0.01451460 | 110 |
| 1953 | 2 | 0.01818180 | 0.01989370 | 110 |
| 1954 | 4 | 0.03636360 | 0.02721140 | 110 |
| 1955 | 4 | 0.03636360 | 0.03711880 | 110 |
| 1956 | 4 | 0.03636360 | 0.05044640 | 110 |
| 1957 | 9 | 0.08181820 | 0.06822030 | 110 |
| 1958 | 14 | 0.127273 | 0.091652 | 110 |
| 1959 | 15 | 0.136364 | 0.122208 | 110 |
| 1960 | 18 | 0.163636 | 0.160815 | 110 |
| 1961 | 21 | 0.190909 | 0.208919 | 110 |
| 1962 | 29 | 0.263636 | 0.266838 | 110 |
| 1963 | 38 | 0.345455 | 0.334033 | 110 |
| 1964 | 51 | 0.463636 | 0.408716 | 110 |
| 1965 | 57 | 0.518182 | 0.487865 | 110 |
| 1966 | 67 | 0.609091 | 0.567627 | 110 |
| 1967 | 72 | 0.654545 | 0.644031 | 110 |
| 1968 | 79 | 0.718182 | 0.713742 | 110 |
| 1969 | 81 | 0.736364 | 0.774579 | 110 |
| 1970 | 84 | 0.763636 | 0.825646 | 110 |

The take-off phase (containing the early adopters) starts in 1952 with the first commercial adoption of BOF and finishes in 1962 as specified from certain technological and economic indicators. Such a specification is supported by technological and economic indicators from literature. Meyer and Herregat (1974) came to the conclusion that by 1961 or 1962 all purely technological problems in adopting BOF had been solved and that all countries and firms were facing a homogeneous technology. Tchijov (1987) concluded that the boundary between the take-off phase and growth phase of different technological life cycles in the case of steel production might be defined as 9-10% of total production. BOF technology reached this ratio in 1962-1963 (Rösch, 1979). During that period (1952-1962), 29 firms adopted BOF.

Figure 4 contains a list of the early adopters of BOF.

FIRMS ADOPTING THE BOF,
1952 - 1962

| FIRM | COUNTRY | DATE | FIRM | COUNTRY | DATE |
|---|---|---|---|---|---|
| Voest | Austria | 11/52 | Hindustani | India | 1/60 |
| Alpine | Austria | 5/53 | Amagasaki | Japan | 8/60 |
| Dofasco | Canada | 10/54 | Fuji | Japan | 10/60 |
| McLouth | U.S. | 12/54 | Sumitomo | Japan | 5/61 |
| Yawata | Japan | 9/57 | C.F.& I. | U.S. | 7/61 |
| Bochumer | W. Germany | 9/57 | S.A.R.L. | Portugal | -/61 |
| Belgo Mineir | Brazil | 10/57 | Kobe | Japan | 11/61 |
| J&L | U.S. | 11/57 | Kawasaki | Japan | 4/62 |
| Petrovski | U.S.S.R. | -/57 | ATH | W. Germany | 6/62 |
| Koninklijke | Netherlands | 1/58 | Norsk | Norway | -/62 |
| Nippon Kokan | Japan | 1/58 | USINOR | France | -/62 |
| Algoma | Canada | 11/58 | Richard Thomas | U.K. | -/62 |
| Kaiser | U.S. | 12/58 | National | U.S. | 9/62 |
| Krivoh Rog | U.S.S.R. | -/58 | Broken Hill | Australia | 12/62 |
| Acme | U.S. | 1/59 | | | |

Source: L. Lynn (1982); J. K. Stone (1966)

Figure 4

Using the standard classifications, we can divide the early adopters into groups as well. The only difficulty is that data on the size of all early adopters are not available. For that reason, we were able to consider only 20 companies (69%). The division of these companies is depicted in Table 3.

**Table 3**

| | Small | Medium | Large | Total |
|---|---|---|---|---|
| Number | 7 | 7 | 6 | 20 |
| Percentage | 35 | 35 | 30 | 100 |

When we compare the results from Tables 1 and 3, we can state that the division into small, medium, and large companies is almost the same. In the group of small companies the percentage (35%) is exactly the same, in the medium group slightly lower (35 versus 42%), and in the large group, on the contrary, slightly higher (30 versus 23%). We can conclude that large companies were slightly more innovative than the medium and small companies.

Studying the process of adopting BOF, we see that at the stage of early adoption, it is very easy to distinguish two main waves. The first lasted from 1952 to 1954, during which 4 companies adopted BOF. After that, there was a 2-year pause and then the second wave from 1957-1962, during which 25 companies adopted this technology. The percentage of companies by size during these two waves is shown in Table 4.

**Table 4**

| | Small | Medium | Large | Total |
|---|---|---|---|---|
| # All E.A. | 26 | 31 | 17 | 74 |
| Percentage | 35 | 42 | 23 | 100 |
| # 1st Wave | 2 | 2 | 0 | 4 |
| Percentage | 50 | 50 | 0 | 100 |
| # 2nd Wave | 5 | 5 | 6 | 16 |
| Percentage | 31 | 31 | 38 | 100 |

From the results, we can see that the small and medium companies began adopting at the same rate (50%) in the first wave, and then were followed by all three groups at almost even rates, with a slight prevalence of the large companies.

In the second step of our analysis, we shall use as an alternative solution the method for clustering points located on the line of real numbers combining histogram and cluster analysis.

The computerized results depicted in Attachment 3 show us the clusters of companies by size. We have 20 clusters and from that can distinguish the differences in production capacity between them. Attachment 4, the histogram, gives us illustrative information about the density and breadth of the "valleys." Combining the results of both the cluster analysis and the histogram allows us to specify **four** main clusters (groups) of companies by size. Using round figures for particular zones, the boundaries of these groups are as follows:

| | |
|---|---|
| small: | up to 999,999 tons |
| medium: | 1,000,000 to 1,999,999 tons |
| large: | 2,000,000 to 5,999,999 tons |
| mammoth: | 6,000,000 tons and over |

We have to add that no exact mathematical method exists for specifying the boundaries, but combining the cluster analysis with the histogram creates the scientific framework for rational expert specification of the boundaries. The first main factor is the breadth of the "valleys" (histogram); the magnitude of the differences between clusters is the second important factor.

The reason why the breadth is more important than the differences in production capacity stems from the results of the cluster analysis. We see that the first clusters (1, 2, 3) with the greatest distances (16,700; 5900; 3499) each contain only one "mammoth" company. Such results are of no use to our analysis. The distance (breadth) between the mammoth size companies and the group of large companies is so large (8,600,000 to 5,101,000 tons) that this in itself implies a homogeneous and natural grouping, without a non-practical division into groups of one isolated mammoth company each. We specified the round figure of 6,000,000 tons as the boundary betwwen mammoth and large companies.

The next largest distance (breadth) is between 2,500,000 and 3,700,000 tons (Cluster No. 4), but this distance is closer to the distances between companies from 3,700,000 and 5,100,000 tons that a more natural grouping is formed by including the company of 2,500,000 tons with the "large" company group. The third largest distance or breadth is found between 1,800,000 and 2,500,000 (Cluster No. 5) and the round figure 2,000,000 tons within that interval creates the boundary between large and medium groups.

Within the small/medium zone on the histogram, the widest valley is found between 700,000 and 1,000,000 tons. Comparing this with the cluster analysis, we use Cluster No. 13 between 900,000 and 1,000,000 tons, specifying the round figure of 1,000,000 tons as the boundary between the groups of small and medium companies (medium from 1,000,000 to 1,999,999 tons and small under 1,000,000 tons).

After specifying the boundaries of the groups, we can continue as in the first step, using the standard boundary classifications. The division of the 74 companies by size and of the 20 early adopters is depicted on Table 5.

**Table 5**

| SIZE | Small | Medium | Large | Mammoth | Total |
|---|---|---|---|---|---|
| Number | 42 | 23 | 6 | 3 | 74 |
| Percentage | 57 | 31 | 8 | 4 | 100 |
| # of E.A. | 10 | 7 | 3 | 0 | 20 |
| % of E.A. | 50 | 35 | 15 | 0 | 100 |

The results of Table 5 show us more distinctly that the group of large companies is almost twice as innovative as the groups of small and medium companies. On the other hand, the group of mammoth companies is completely non-innovative.

Analyzing the two main waves in the period of early adoption, we obtain the results depicted in Table 6.

**Table 6**

| SIZE | Small | Medium | Large | Mammoth | Total |
|---|---|---|---|---|---|
| All comp. | 42 | 23 | 6 | 3 | 74 |
| Percentage | 57 | 31 | 8 | 4 | 100 |
| # 1st Wave | 4 | 0 | 0 | 0 | 4 |
| Percentage | 100 | 0 | 0 | 0 | 100 |
| # 2nd Wave | 6 | 7 | 3 | 0 | 16 |
| Percentage | 37 | 44 | 19 | 0 | 100 |

From the results of Table 6, we can again see more distinctly that the small companies started the adoption of BOF only later to be followed by medium and especially large companies, where the share was almost 2.5 times higher than the rate of the number of companies (19 versus 8%).

From the results of this analysis, mainly from its second step, we conclude that from a global point of view all size groups, except mammoth, took part in the early process of adopting BOF. The relatively higher share was that of the large companies, but the process began with the small companies.

Looking at the problem of innovativeness by company size from a national point of view, we can analyze the countries for which data are available, i.e. Australia, Austria, Canada, USA, FRG, Brazil, Netherlands, Norway, France, and Japan.

In **Australia**, only one company, Broken Hill, had the preconditions to adopt BOF and realized it. The firm is the country's largest steel company.

In **Austria**, we see that only two companies (Voest and Alpine) had the preconditions to adopt BOF, and both did. The firms have since merged and are Austria's largest steel entities.

In **Canada**, four companies would have been able to adopt BOF. Only two or 50% actually did; the smallest (Dofasco) and the largest (Algoma).

In the **USA**, the situation is shown in Table 7. From a total of 20 integrated steel companies, 6 or 30%[13] adopted BOF early on.

**Table 7**

| | Small | Medium | Large | Total |
|---|---|---|---|---|
| Integ.Comp. | 1 | 9 | 10 | 20 |
| Percentage | 5 | 45 | 50 | 100 |
| Early Adop. | 1 | 1 | 3 | 5 |
| Percentage | 20 | 20 | 60 | 100 |

From this table, we see that the group of small companies is the most innovative (5% - 20%), followed by large companies (50%-60%). Only minor innovativeness is shown by the group of medium size companies (45% - 20%).

In the **Federal Republic of Germany**, only one firm (A.T.H.) is considered[14] (about 12%). The firm is the smallest steel company in the country.

In **Brazil**, only two firms had the possibility of adopting BOF; one, Belgo-Mineira, or 50% did in fact. From a global point of view, the firm is small, but it is Brazil's largest steel company.

In the **Netherlands**, the only firm capable of adopting BOF did. Globally, it is also considered small, but it is the country's largest.

In **Norway**, the situation is the same. Only one firm was able to adopt BOF, it did, and is its country's largest.

In **France**, three firms had the capability to adopt BOF. Only one, USINOR, did (33%). It is the second largest steel company in France; from a global point of view, a medium company.

In **Japan**, the situation is very illustrative. Out of a total of 5 companies,[15] all belong to the group of early adopters. One company is small, two are medium, and two are large.

---

[13]Data unavailable for Acme Steel.

[14]Data unavailable from Bochumer.

[15]Data unavailable from Sumitomo and Amagasaki.

From this survey of 10 countries, we can state that in most of them, the early adopters were the largest steel companies from a national point of view (Austria, Australia, Brazil, Netherlands, Norway, France [2nd largest]). In one country, Canada, the early adopters were the smallest and the largest companies; in Japan, all integrated steel companies were early adopters. The only exceptions are the FRG, where the early adopter was a small company and the USA where the percentage of small companies as early adopters is the highest.

The next topic is the relationship between company age and innovativeness. From Attachment 2, we see that we do not have a great deal of data available. So the findings cannot be very significant statistically, and the results are assumed only to be illustrative of the situation. From the total of 74 companies, we know the year of establishment of 27. Fifteen are early adopters of BOF, i.e. over 50%. If we divide the time from the first adoption of BOF (1952) into 10-year periods backwards and analyze the data, we obtain the results depicted on Table 8.

**Table 8**

| | 1952 TO 1943 | 1942 TO 1933 | 1932 TO 1923 | 1922 TO 1913 | 1912 TO 1903 | 1902 TO 1893 | 1892 TO 1883 | 1882 TO 1873 | TOTAL |
|---|---|---|---|---|---|---|---|---|---|
| ALL COMPANIES | 5 | 4 | 0 | 4 | 4 | 5 | 3 | 2 | 27 |
| PERCENTAGE | 18 | 15 | 0 | 15 | 15 | 18 | 11 | 8 | 100 |
| EARLY ADOPTERS | 3 | 3 | 0 | 3 | 3 | 0 | 2 | 1 | 15 |
| PERCENTAGE | 20 | 20 | 0 | 20 | 20 | 0 | 13 | 7 | 100 |

The results show that the percentage of the early adopters is slightly higher than that of all companies, and that there is no indication that young companies (1952-1943) are more innovative than older ones. The exception is the period 1893-1902. Not one of the 5 companies established during those years belongs to the group of early adopters. We have no logical explanation for this phenomenon. For the earliest period (1873-1882), the percentage of early adopters is slightly lower, but on the other hand the period contains one company (Alpine) from the "first wave."

## 5. DISCUSSION

At the outset, it is necessary to stress that the results achieved have been acquired from a very narrow sample of one innovation in steel-making technology, albeit one of the most significant and decisive industrial events during the last 35 years. It is necessary to evaluate the outcomes, bearing this in mind. All these facts should be considered prior to drawing concrete conclusions from the results. Furthermore, the relatively narrow data base also does not permit broad generalizations in formulating our conclusions.

The main aim of this study was to verify the different hypotheses regarding the relationship between company size/age and innovative activity. Our research aimed to investigate the possible concrete implications of the results on management decision-making, especially in the area of strategic management, as well. The idea was, in conjunction with the aims of the MTL activity and other recommendations, e.g. directions for further research done by Buzacott (1980), to analyze the optimal company size and age closely with regard to innovative activity.

The aim of such findings is clear. These results can pave the way for better strategic decisions, not only on the company level. To specify the role of company size could be important, for example, for governmental policy, bank intervention, as well as for a company's own investment strategy and strategic management of innovation technology. Government as well as bank policy can differentiate their support of companies using, among others, the criteria of size and age. Governmental bodies and banks can use differentiating instruments such as direct R&D funding, conditional repayment loans, cooperative research programs, pricing (in planned economies), high-risk loans, patent policies, tax deductions, standards and regulations; education/training/re-training funding, and export credits in favor of those companies whose probability of innovative activity is higher.

An analysis of the results of our study, a comparison of the results of the first and second steps (Tables 3 and 4), and especially the results of the second step show most clearly that the most innovative group in the case of BOF adoption was the group of large companies, twice as high as the groups of small and medium companies. The results partially prove Wilson's theory and the conclusions of the IIASA workshop (1979) "Size and Productive Efficiency: The Wider Implications" in that the optimal size lies somewhere between the two outer extremes. But in our case, it is very important to recognize that the take-off phase of the technological life cycle was started by the small companies. On the other hand, we also see the complete lack of early innovativeness on the part of the mammoth companies. These are the facts which must be taken into consideration in strategic decision-making.

A further fact must also be considered. The above mentioned conclusions are made up for the take-off phase of the technological life cycle. In the following phases, the situation could be (and most probably is) very different. So government, bank and company strategic policy must take into account size as a factor of time (the different phases of the technological life cycle) as well.

Our results have not yet proven the other hypothesis (see Table 7) that young companies are more innovative than older ones. But another most important result arises from our investigation. The size and age of companies is usually studied from a global point of view, but strategic policy usually functions on the company or country level (the steel industry is not a typical case of multinational companies).

The first conceptual problem is that one company may belong to the group of small firms from a global point of view, and at the same represent the largest company in its own country (Alpine in Austria, Belgo-Mineira in Brazil, etc.). More than this conceptual problem, a crucial challenge arises. Many of the small and medium size countries (Austria, Netherlands, Norway) or large countries with less developed steel industry (Australia, Brazil) had no choice as to which firm to support, because in these countries only 1 or at the most 2 companies had the capability to adopt BOF. So, for this size or type of country, the results have primarily a methodological significance for application in other branches of industry, where the number of companies of different sizes is higher.

Comparing size with certain other factors influencing strategic decision-making in the adoption of BOF in some of the countries described in literature or in the MTL questionnaire, we make the following statements:

In **Austria**, we can denote as the main factors environmental conditions and favorable technological preconditions. As an important environmental precondition, we can indicate the lack of steel on the national and world market during that period, lack of the necessary scrap supply and as technological prerequisite a nitrogen-producing plant at that company (Voest) that generated oxygen as a by-product. The introduction of BOF promised to increase output of steel production together with decreasing scrap consumption. Moreover, no additional investments for a new oxygen generating plant were necessary. Company size played a negligiable role in making this strategic decision.

In the **USA**, the situation concerning the adoption of BOF was very complicated and we can agree with Lynn (1982) that it raises the notion of the so-called "garbage can" model, describing decision-making in "organized anarchies." The decision process is seen as a confluence of relatively independent streams of solutions, problems, choice opportunities and participants. Different authors present different reasons for the adoption, or rather the late adoption, of BOF by U.S. firms.

Schenk (1974) assumes that there is a striking simularity between the diffusion of continuous casting and that of the BOF in the U.S. One of the reasons for the relatively late introduction of the BOF by large American steel plants seems to have been that it took some time to develop a LD-converter of sufficient capacity. This is confirmed by Meyer and Herregat (1974) that by the end of 1954, there were four plants worldwide using oxygen converters of the following capacity: two 30-ton vessels (Voest and Alpine, Austria), 35-ton vessel (Dofasco, Canada), and 35-ton vessel (McLouth, USA). But the results of our study show that this is only partially true (See Table 7) because large companies are the second most innovative group (60% of early adopters compared with 50% of total number of large companies).

Lynn (1982) sees the main reason for the late adoption of BOF, among others, in the negative role of the main suppliers. U.S. suppliers did not function as well in the promotion and development of BOF as, for example, those in Japan. The introduction of the BOF offered clear advantages to the steelmakers, but not necessarily to the suppliers. The refractories industry had to change their plants to produce refractories for the BOF's, but consumption fell substantially because BOF uses fewer refractories than the open hearth method. The largest U.S. steel plant engineering firm had a heavy investment in open hearth technology and no reason to want to see a shift away from open hearths. In the U.S., there was no governmental body to promote the early adoption of BOF with financial and technical assistance.

Ray (1984) is of the opinion that there is a minimum size for an economical BOF plant which is certainly considerably more than one million and probably around three million tons. But we must take into account that such a conclusion has been drawn for the maturity and declining phases of the BOF life cycle (late 1960's to the present) and has not been applied in take-off or growth phases.

Buzacott (1980) stressed the economic climate and environment and drew the conclusion that it was "bad luck" for the U.S. steel industry that it expanded during the Korean War boom and hence had such a surplus capacity afterwards that major expansion of capacity was not required.

From this survey of different factors influencing adoption of BOF in the U.S., we can see the great complexity of the analysis of management, especially strategic or innovation management.

We can examine certain correlations between the adoption of BOF and that of continuous casting (See Figure 5), where 3 of 5 (60%) early adopters of BOF adopted continuous casting (CC) during the first phase in the U.S. (1963-1971). McLouth adopted CC in 1964, J&L in 1968, National in 1969. On the other hand, many late adopters of BOF adopted CC in this first stage as well, including "mammoth size" companies (U.S. Steel in 1967, Republic in 1968, and Bethlehem in 1970).

Firms Adopting the CC in the U.S.
1963-1971

| FIRM | YEAR | FIRM | YEAR |
|---|---|---|---|
| Roanoke | 1963 | Laclede | 1967 |
| H.K. Porter | 1964 | North Star | 1967 |
| Roblin | 1964 | J & L | 1968 |
| McLouth | 1964 | Weirton | 1968 |
| Armco | 1965 | Phoenix | 1968 |
| Copperweld | 1965 | Pollak | 1968 |
| Florida | 1965 | Republic | 1968 |
| Wickwire Brothers | 1965 | Timker Roller Bearing | 1968 |
| Soule | 1966 | National | 1969 |
| Wisconsin | 1966 | Nuclear | 1969 |
| U.S. Steel | 1967 | Georgetown | 1969 |
| Tennessee Forging | 1967 | Bethlehem | 1970 |
| Borg Warner | 1967 | Inland | 1971 |
| Etiwanda | 1967 | | |

Source: D. A. Muettner (1974)

**Figure 5**

A different situation analyzes production growth of early and late adopters of BOF for the period 1951-1965 (see Figure 6).

| COMPANY | PRODUCTION 1951 (mil t) | PRODUCTION 1965 (mil t) | INDEX 65/51 |
|---|---|---|---|
| **Early Adopters:** | | | |
| J & L | 4.4 | 6.6 | 1.50 |
| National | 4.3 | 7.7 | 1.79 |
| Kaiser | 1.1 | 2.5 | 2.27 |
| C. F. & I. | 1.5 | 1.5 | 1.00 |
| McLouth | 0.4 (est.) | 1.5 | 3.75 |
| TOTAL | 11.7 | 19.8 | 1.69 |
| **Late Adopters:** | | | |
| U.S. Steel | 31.2 | 29.6 | 0.95 |
| Bethlehem | 14.5 | 19.1 | 1.32 |
| Republic | 8.6 | 9.0 | 1.05 |
| Youngtown | 4.0 | 5.4 | 1.35 |
| Armco | 4.0 | 7.1 | 1.78 |
| Inland | 3.5 | 5.9 | 1.69 |
| Wheeling | 1.7 | 1.9 | 1.12 |
| Sharon | 1.5 | 0.9 | 0.60 |
| Crucible | 1.1 | 1.2 | 1.09 |
| Pittsburgh | 1.0 | 1.4 | 1.40 |
| TOTAL | 71.1 | 81.5 | 1.15 |

Source: L. H. Lynn (1982)

**Figure 6**

From Figure 6, we discover that in the group of the early adopters, the maximum index is 3.75 (McLouth, the first adapter in the U.S.) and the minimum is 1.00 (C.F. & I.). The average production growth index of this group is 1.69.

In the group of late adopters, the maximum index is 1.78 (Armco) and the minimum is 0.60 (Sharon). The average production growth is 1.15.

We see that the group of early adopters has better results compared with late adopters. The results could be further improved by the quality of management, but the main role is played by the use of a new BOF technology proven to be better than either Bessemer or Open Hearth. Only electric furnaces can compete with BOF, and that under very special conditions (e.g. small production volume, special grades of steel, low scrap and electric energy prices). But such evidence became known after the take-off phase of the BOF technological life cycle.

The complicated conditions described above may have resulted in the decision of many small companies to adopt BOF, because the risk for them was not so high. Rosegger (1980) confirms that "expectations of cost advantages in the BOF plant alone would have constituted a thin reed on which to hang the commitment of a multi-million dollar investment."

In **Japan**, one of the main reasons for such a broad early adoption of BOF is the role of government and governmental bodies, mainly the Ministry of International Trade and Industry (MITI) and supplying companies. MITI engineers strongly promoted the BOF and made sure that the information and experience gained by one firm was quickly available to all. As Lynn (1982) remarks, no comparable role was played by any U.S. government agency. The companies in Japan were stronger in relation to their suppliers and were therefore able to take more initiative in technological changes.

In **Canada**, the first adopter, Dofasco, found itself in the following situation in 1953: its open hearth capacity was being fully utilized and its blast furnace had surplus capacity (Buzacott, 1980). In contrast to almost all U.S. companies, it had not expanded its steel-making facilities at the beginning of the Korean War rearmament boom in 1950-51. When BOF appeared, Dofasco was in the unique situation of requiring more steel-making capacity and having the particular size, rate of growth, and production assortment for which the new process was ideal.

In the **USSR** and other Eastern countries, the process of adopting BOF progressed more slowly. According to Marcus and Levy (1976), there are three main reasons for this lagging behind:

* less rigourous pollution standards in many Eastern countries;

* lack of the profit motive as an incentive when it came time to replace obsolete equipment;
* inherent shortages of pig iron, while BOF requires a higher ratio of molden pig iron.

According to Buzacott (1980), the persistance and further development of the open hearth by the Soviet steel industry may have been due to their having large steel plants with absolute growth rates. There may have been a long delay until the niche for the introduction of BOF appeared.

Aichinger, Hoffmann and Pittel (1981) have estimated the development of steel-making processes through 2000 (see Figure 7). They prognosize that BOF in the year 2000 will be in prevalent use throughout the world.

| | OXYGEN | ELECTRIC | OPEN HEARTH | THOMAS, ETC. |
|---|---|---|---|---|
| **European Community** | | | | |
| 1967 | 28 | 13 | 34 | 25 |
| 1979/80 | 72 | 23 | 5 | -- |
| 2000 | 75 | 25 | -- | -- |
| **North America** | | | | |
| 1967 | 32 | 13 | 55 | -- |
| 1979/80 | 61 | 24 | 15 | -- |
| 2000 | 70 | 25 | 5 | -- |
| **Japan** | | | | |
| 1967 | 67 | 18 | 15 | -- |
| 1979/80 | 76 | 24 | -- | -- |
| 2000 | 80 | 20 | -- | -- |
| **USSR & Eastern Countries** | | | | |
| 1967 | 9 | 9 | 80 | 2 |
| 1979/80 | 30 | 12 | 58 | -- |
| 2000 | 53 | 22 | 25 | -- |
| **World** | | | | |
| 1967 | 27 | 15 | 51 | -- |
| 1979/80 | 52 | 24 | 24 | -- |
| 2000 | 61 | 29 | 10 | -- |

Source: Aichinger, Hoffmann, & Pittel, 1981

Figure 7

## 6. CONCLUSIONS

A basic question could be raised in conclusion. When a technology is in the maturity or post-maturity phases (as BOF is at present), are these results applicable? The answer follows: this study carries primarily a methodological significance which can be applied not only in the steel industry to other technologies (i.e., continuous casting), but in other industries as well.

Moreover, the adoption of BOF technology has not yet been completed. We have many examples, not just in developing countries, but in developed countries both East and West as well (France, Czechoslovakia, FRG, Portugal, USSR) in which BOF has been adopted since 1981.

As a suggestion for further research in this area, it would be of great value to continue the research through the other phases of the technological life cycle (growth, maturity, and post-maturity) and compare the results with our findings. It is now, of course, a question of obtaining data for these phases.

In order to generalize the results of our study, it would be necessary to test the achieved results not only for other innovation technologies in the steel industry (e.g. continuous casting), but for innovation technologies in other industries as well (e.g. CIM in mechanical engineering, adoption of IR, etc.).

# ATTACHMENTS

ATTACHMENT 1.

## DESCRIPTION OF METHOD OF CLUSTER ANALYSIS
by Sadaaki Miyamoto

The description of this method follows:

1. Let us consider the following situation. Suppose we have n data points of real numbers $x_1$, $x_2$, ...., $x_n$ (Figure 1). For simplicity, we assume $x_1 < x_2 < \ldots < x_n$. In general, it may occur that $x_i = x_{i+1} = \ldots = x_{i+k}$. However, it is straightforward to extend the method which will be described below to the case when we have two or more sample points of the same value.

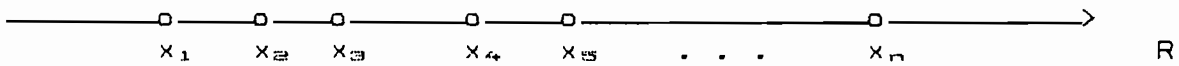



Figure 1

Then we consider the following (vaguely defined) problem. We wish to classify these points into a number of categories so that the distance between a pair of points within a category is small and also the distance between two points from different categories is large. Moreover, the number of categories is not given as a prior information. Our purpose in this note is to design an appropriate method for this problem.

The above problem can be treated in two ways. The first way is to apply a method of cluster analysis; the second way is to use a histogram of the data points.

2. In cluster analysis, we have many alternative choices of similarities and the algorithms. In this case, the most natural measure of similarity (in fact, dissimilarity) is the distance between a pair of elements $x_i$ and $x_j$ : $d(x_i,x_j) = |x_i - x_j|$. Moreover, one of the most standard algorithms for generating clusters is to introduce a threshold d (d>0) and to determine a cluster $C^k_d$:

$$x_i,\ x_{i-1} \in C^k_d \qquad \text{if and only if} \qquad d(x_i,x_{i-1}) \le d.$$

Of course, the family of subset $\{C^k_d\}_k$ makes a partition of the set $X = \{x_1, \ldots, x_n\}$: $\cup_k C^k_d = X$. Furthermore, for two values $d_1 > d_2$, $\{C^k_{d2}\}_k$ is a refinement of $\{C^k_{d1}\}_k$. If we move the parameter d from zero to $max_i(x_i - x_{i-1})$, we have a sequence of the partitions of X that agrees with the result of application of the single linkage method. Therefore, one of the most natural clustering is the single linkage method in this case. Moreover, the above method has a close relation to a method of histogram.

3. On the other hand, a standard method of histogram can be described as follows. Divide the interval that contains the whole data points into N subintervals of equal length. Calculate number of points in each subinterval. Make a bar in each subinterval the height of which is proportional to the number of points included in that subinterval.

   If one obtains a histogram in a satisfactory way, it is easy to define categories. Find valleys in the histogram and divide the data set at the bottom of the valleys.

   This method of histogram, however, has several drawbacks. First, we frequently cannot determine an appropriate value of N for subintervals. Different values of N would give different shapes of histograms. If we have a great number of data points, the histogram will be stable, but in the case of a small number, say less than one hundred, the above problem will be serious. Secondly, if we have a small valley in the histogram, we cannot decide definitely whether or not that is a true valley. In general, the histogram method is more suitable for a large number of data points; the clustering method is more appropriate for a small number of data points.

4. Fortunately, in this situation of data points on a line, we have a better method of histogram that completely agrees with the above method of clustering. The method is based on the "filling in" between a pair of contiguous points. The method is very simple: For all $x_i$, make a square between two points $x_i$ and $x_{i+1}$ whose height is $1/(n|x_{i+1} - x_i|)$ and whose width is $|x_{i+1} - x_i|$ (Figure 2).

   To define categories, let **b** be a variable threshold parameter. Let b move from zero to $max_i\ 1/n(|x_i - x_{i-1}|)$. Then, at the value $b = min_i\ 1/(n|x_i - x_{i-1}|)$, two subsets of data points are separated at the lowest valley of the histogram. As **b** becomes larger, the number of categories will also be larger.

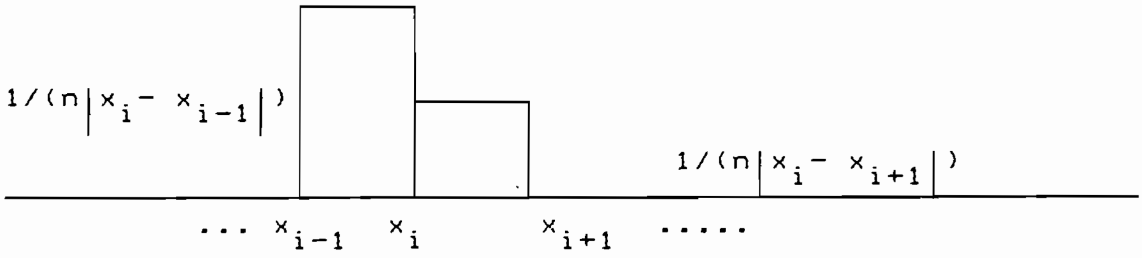



Figure 2

It is straightforward to see that the last method of the histogram is equivalent to the first method of the clustering. Two thresholds are related as 1/d=nb.

It remains to prove that the last method is indeed a method of histogram. For this it is sufficient to show that for any subinterval [r,s] (cR), the area made by the last method converges to $\int_r^s p(x)dx$ as the number n of data points goes to infinity, where p(x) is assumed to be the "true" density function from which samples have been obtained.

The proof is very simple. Let $n_{rs}$ be the number of points that are included in the subinterval [r,s]. From the assumption, we have

$$n_{rs}/n \quad \rightarrow \quad \int_r^s p(x)dx \quad \text{as} \quad n \quad \rightarrow \quad \infty$$

Since the area between two contiguous points $x_{i+1}$ and $x_i$ is equal to $|x_{i+1} - x_i| \times 1/(n|x_{i+1} - x_i|) = 1/n$, the area $s_{rs}$ made by the last method of the histogram satisfies

$$(n_{rs} - 1)/n \leq s_{rs} < (n_{rs} + 1)/n$$

from which it follows that

$$s_{rs} \quad \rightarrow \quad \int_r^s p(x)dx \quad \text{as} \quad n \quad \rightarrow \quad \infty$$

Unfortunately, the above relation of equivalence between the method of the clustering and that of the histogram cannot be generalized to two or more dimensional spaces. Nevertheless, some heuristic generalizations can be considered as future studies.

ATTACHMENT 2.

INTEGRATED STEEL COMPANIES -- YEAR 1951 -- COMPANY SIZE AND AGE

| COUNTRY | NAME OF THE COMPANY | YEAR OF ESTABL. | RAW STEEL CAPACITY (TONS/YEAR) | YEAR OF BOF ADOPTION | REF. NUM. |
|---|---|---|---|---|---|
| Australia | Broken Hill Proprietary Co. Ltd. | 1885 | 1,870,000 | 1962 | 3,1,2 |
| Austria | Alpine (Oest.-Alpine Montangesellschaft) | 1881 | 510,000 | 1953 | 1,4,2 |
| Austria | VOEST (Vereinigte Oest. Eisen-und Stahlwerke | 1938 | 390,000 | 1952 | 1,4,2 |
| Belgium | S.A. Metallurgique de Sambre et Mosele | -- | 480,000 | | 1 |
| Brazil | Companhia Brasileira de Usinas Metalurgicas | -- | 38,000 ** | | 1 |
| Brazil | Companhia Siderurgica Belgo-Mineira | 1921 | 146,000 | 1957 | 1,2 |
| Canada | Algoma Steel Corp. | 1934 | 1,249,000 * | | 1,3,2 |
| Canada | DOFASCO (Dominion Foundries & Steel, Ltd.) | 1912 | 550,000 | 1954 | 1,2 |
| Canada | DOSCO (Dominion Steel & Coal Corp, Ltd.) | -- | 840,000 | | 1 |
| Canada | STELCO (Steel Co. of Canada, Ltd.) | 1910 | 1,246,000 | | 1,2 |
| China | Tai-Yuan Iron & Steel Works | -- | 117,000 *** | | 1 |
| France | Societe de Wendel et Cie. | -- | 1,330,000 * | | 1 |
| France | Sollac & UCPMI | 1948 | 500,000 | | 1,2 |
| France | USINOR | 1948 | 1,110,000 | | 1,2 |
| FRG | August-Thyssen Huette | 1890 | 117,000 | 1962 | 1,2 |
| FRG | Dortmund-Hoerder Huettenunion AG | -- | 1,855,000 | | 1 |
| FRG | Huettenwerk Oberhausen AG | -- | 1,285,000 | | 1 |
| FRG | Huettenwerk Rheinhausen AG | -- | 1,450,000 | | 1 |
| FRG | Huettenwerke Ruhrort-Meiderich AG | -- | 1,656,000 | | 1 |
| FRG | Mannesmann Huettenwerke AG | 1890 | 777,000 | | 1,2 |
| FRG | Niederrheinische Huette AG | -- | 396,000 | | 1 |
| FRG | Stahlwerke Suedwestfalen AG | -- | 174,000 | | 1 |
| GDR | Max-Huette | -- | 240,000 * | | 1 |
| Hungary | Diosgyor Iron & Steel Works | -- | 300,000 | | 1 |
| Hungary | Ozd Iron & Steel Works | -- | 420,000 | | 1 |
| Japan | Fuji Iron & Steel Co. Ltd. | -- | 1,687,000 | 1960 | 3,1 |
| Japan | Kawasaki Steel Corp. | 1950 | 597,000 | 1962 | 3,1,2 |
| Japan | Kobe (Kobe Seiko Sho) | 1911 | 327,700 | 1961 | 3,1,2 |
| Japan | Nakayama Steel Works, Ltd. | -- | 177,400 | | 1 |
| Japan | NKK (Nippon Kokan Kabushiki Kaisha) | 1912 | 1,234,000 | | 3,1,2 |
| Japan | Yawata Iron & Steel Co. Ltd. | -- | 2,504,900 | 1957 | 3,1 |
| Luxembourg | Arbed S.A. | 1882 | 1,100,000 | | 1,2 |
| Luxembourg | Hadir | -- | 900,000 | | 1 |
| Luxembourg | Miniere et Metallurgique de Rodange, S.A. | 1972 | 400,000 | | 1,2 |
| Mexico | Altos Hornos de Mexico, S.A. | 1942 | 170,000 | | 1,2 |
| Mexico | Cia. Fundidora de Hierro y Accero de Monterre | 1943 | 225,000 | | 1,2 |
| Netherlands | Koninkligke Nederlandsche Hoogovens en Staalf | 1918 | 400,000 | 1958 | 1,2 |
| Norway | A/S Norsk Jernverk | 1946 | 400,000 | 1962 | 1,2 |
| Sweden | Domnarfvets Jernverk | -- | 500,000 | | 1 |
| Sweden | Hellefors Bruks AB | -- | 56,000 | | 1 |
| Sweden | Norrbottens Jaernverk, AB | -- | 350,000 | | 1 |
| Sweden | SKF (Aktiebolaget Svenska Kullager Fabriken H | -- | 160,000 | | 1 |

ATTACHMENT 2 (CON'T)

| | | | | | |
|---|---|---|---|---|---|
| U.K. | Colvilles Ltd. | -- | 1,518,000 | | 1 |
| U.K. | Consett Iron Company Ltd. | -- | 600,000 | | 1 |
| U.K. | Guest Keen Baldwins Iron & Steel Co. | -- | 617,000 * | | 1 |
| U.K. | Parkgate Iron & Steel Co. | -- | 325,000 | | 1 |
| U.K. | Shelton Iron, Steel & Coal Co. | -- | 225,000 | | 1 |
| U.K. | Skinningrove Iron Co. | -- | 320,000 | | 1 |
| U.K. | Steel Co. of Scotland, Ltd. | -- | 340,000 | | 1 |
| U.K. | Steel Co. of Wales | -- | 9,500,000 | | 1 |
| U.K. | Stewarts & Lloyds | -- | 700,000 | | 1 |
| U.K. | Workington Iron & Steel Co. | -- | 280,000 * | | 1 |
| U.S.A. | Armco Steel Corp. | 1900 | 4,000,000 * | | 3,2 |
| U.S.A. | Bethlehem Steel Co. | 1919 | 14,500,000 * | | 3,2 |
| U.S.A. | Crucible Steel Co. of America | -- | 1,095,000 | | 1,3 |
| U.S.A. | C.F.&I. (Colorado Fuel & Iron Corp) | -- | 1,560,000 | 1961 | 1 |
| U.S.A. | Detroit Steel Corp. | -- | 650,000 | | 1 |
| U.S.A. | Ford Motor Company | -- | 1,471,940 | | 1 |
| U.S.A. | Granite City Steel Corp. | -- | 720,000 | | 1 |
| U.S.A. | Inland Steel Company | 1893 | 3,750,000 | | 1,2 |
| U.S.A. | International Harvestor Co. | -- | 900,000 | | 1 |
| U.S.A. | Jones & Laughlin Steel Corp. | 1922 | 5,101,000 | | 1,3,2 |
| U.S.A. | Kaiser Steel Corp. | 1941 | 1,100,000 * | 1958 | 3,2 |
| U.S.A. | McLouth Steel Corp. | 1982 | 420,000 | 1954 | 1,3,2 |
| U.S.A. | National Steel Corp. | -- | 4,750,000 | 1962 | 1,3 |
| U.S.A. | Newport Steel Corp. | 1981 | 704,000 | | 1 |
| U.S.A. | Pittsburgh Steel Co. | -- | 1,072,000 | | 1 |
| U.S.A. | Republic Steel Corp. | 1899 | 8,600,000 * | | 1,2 |
| U.S.A. | Sharon Steel Corp. | 1900 | 1,441,400 | | 1,3,2 |
| U.S.A. | US Steel (United States Steel Corp.) | 1901 | 31,200,000 * | | 3,2 |
| U.S.A. | Wheeling Steel Corp. | 1968 | 1,860,000 | | 1,3,2 |
| U.S.A. | Youngstown Sheet & Tube Co. | -- | 4,350,000 | | 1,3 |
| U.S.S.R. | Azovstal Metallurgical Works | -- | 1,000,000 | | 1 |
| U.S.S.R. | Kirov Iron & Steel Works | -- | 1,000,000 | | 1 |

* Production
** Production in 1950
*** Production in 1945

## ATTACHMENT 3
## Cluster Analysis

Column 1:
Production Capacity

Column 2:
Distance between
Production Capacities

| | | | |
|---|---|---|---|
| brazil brasileira | 39 | 47 | SMALL |
| sweden hellefors | 56 | 61 | |
| *** 16 ********** | | | |
| frd #62 august | 117 | 0 | |
| china tai-yuan | 117 | 29 | |
| brazil #57 s.b.m | 146 | 14 | |
| sweden skf | 160 | 10 | |
| mexico ahm | 170 | 4 | |
| frd sudwestfallen | 174 | 3 | |
| japan nakayama | 177 | 48 | |
| mexico cia | 225 | 0 | |
| uk shelton | 225 | 15 | |
| gdr max-hutte | 240 | 41 | |
| uk workington | 281 | 39 | |
| uk skinningrove | 320 | 5 | |
| uk parkgate | 325 | 3 | |
| japan #61 kobe | 328 | 12 | |
| uk scotland | 340 | 10 | |
| sweden norrbottens | 350 | 40 | |
| austria #52 voest | 390 | 6 | |
| frd niederrheinishe | 396 | 4 | |
| norway #62 a/s | 400 | 0 | |
| luxembourg miniere | 400 | 0 | |
| netherlands #58 k.n | 400 | 20 | |
| usa #54 mclouth | 420 | 0 | |
| hungary ozd | 420 | 60 | |
| *** 18 ********** | | | |
| belgium s.a.m.s.m | 480 | 20 | |
| sweden domnarfvets | 500 | 0 | |
| france sollac | 500 | 50 | |
| canada #54 dofasco | 550 | 20 | |
| austria #53 alpine | 570 | 27 | |
| japan #62 kawasaki | 597 | 3 | |
| uk consett | 600 | 17 | |
| uk balduins | 617 | 33 | |
| usa detroit | 650 | 50 | |
| *** 20 ********** | | | |
| uk stewarts | 700 | 4 | |
| usa newport | 704 | 16 | |
| usa granite | 720 | 57 | |
| *** 19 ********** | | | |
| frd mannesmann | 777 | 23 | |
| hungary diosgyor | 800 | 40 | |
| canada dosco | 840 | 60 | |
| *** 17 ********** | | | |
| usa intl harvester | 900 | 0 | |
| luxembourg hadir | 900 | 100 | |
| *** 13 ********** | | | |
| ussr azoustal | 1000 | 0 | MEDIUM |
| ussr kirov | 1000 | 72 | |
| *** 15 ********** | | | |
| usa pittsburgh | 1072 | 23 | |
| usa crucible | 1095 | 5 | |
| usa #58 kaiser | 1100 | 0 | |
| luxenbourg arbed | 1100 | 10 | |
| france usinor | 1110 | 124 | |
| *** 11 ********** | | | |
| japan nkk | 1234 | 11 | |
| canada algoma | 1245 | 1 | |
| canada stelco | 1246 | 39 | |
| frd oberhausen | 1285 | 45 | |
| france wendel | 1330 | 111 | |
| *** 12 ********** | | | |
| usa sharon steel | 1441 | 9 | |
| frd rheinhausen | 1450 | 28 | |
| usa ford | 1478 | 22 | |
| uk wales | 1500 | 18 | |
| uk colvilles | 1518 | 42 | |
| usa #61 colorado | 1560 | 96 | |
| *** 14 ********** | | | |
| frd meiderich | 1656 | 31 | |
| japan #60 fuji | 1687 | 168 | |
| *** 10 ********** | | | |
| frd dortmund | 1855 | 5 | |
| usa wheeling steel | 1860 | 10 | |
| australia #62 b.h.p | 1870 | 635 | |
| *** 5 ********** | | | |
| japan #57 yawata | 2505 | 1245 | LARGE |
| *** 4 ********** | | | |
| usa inland steel | 3750 | 250 | |
| *** 9 ********** | | | |
| usa armco | 4000 | 350 | |
| *** 8 ********** | | | |
| usa youngstown | 4350 | 400 | |
| *** 6 ********** | | | |
| usa #62 national | 4750 | 351 | |
| *** 7 ********** | | | |
| usa j and l | 5101 | 3499 | |
| *** 3 ********** | | | |
| usa republic | 8600 | 5900 | MAMMOTH |
| *** 2 ********** | | | |
| usa bethlehem | 14500 | 16700 | |
| *** 1 ********** | | | |
| usa us steel | 31200 | 0 | |

ATTACHMENT 4
Histogram

```
    0 **
  100 *******
  200 ****
  300 *******
  400 ******          SMALL
  500 *****
  600 ***
  700 ****
  800 **
  900 **                             SMALL/MEDIUM
 1000 ****
 1100 ***
 1200 ****
 1300 *
 1400 ***             MEDIUM
 1500 ***
 1600 **
 1700
 1800 ***
 1900
 2000
 2100
 2200
 2300
 2400
 2500 *
 2600
 2700
 2800
 2900
 3000
 3100
 3200
 3300
 3400
 3500
 3600
 3700 *
 3800
 3900
 4000 *                     LARGE
 4100
 4200
 4300 *
 4400
 4500
 4600
 4700 *
 4800
 4900
 5000
 5100 *
 5200
 5300
 5400
 5500
 5600
 5700
 5800
 5900
 . . .
 . . .
 . . .
 8600 *
14500 *               MAMMOTH
31200 *
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