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A dynamic model for the diffusion of ISO 9000 and ISO 14000 standards[1]

Marimon Viadiu, Frederic[1]; Casadesús Fa, Martí[2]; Heras Saizarbitoria , Iñaki[3]

[1] Universitat Internacional de Catalunya fmarimon@unica.edu
[2] Universitat de Girona marti.casadesus@udg.es
[3] Universidad del País Vasco oephesai@sc.ehu.es

SUMMARY

At the global scale, the evolution of the ISO 9000 and ISO 14000 certifications has expanded following the pattern indicated by the logistic curve. This article presents the basic principles behind the growth model based on this curve, and develops the model through two different languages. One of these is an Excel-type spreadsheet; the other is that of the PSPS -Programa Simulador de Pequeños Sistemas (Small Systems Program Simulator) - itself. The behaviour of both versions of the logistic model is consistent with that defined by the equation of the said curve.

Key words: *Diffusion, ISO 9000, ISO 14000, logistic curve.*

1.- Introduction.

The ISO 9000 norms began its massive implementation at the early '90. Actually, the norm had a key role in order to introduce new concepts related to the quality management along the last decade of the past century. The academic literature links these years to the third era of the history of the quality management: the assured quality era. ISO 9000 was popularised in the middle of the decade. Recently it has been introduced the fourth era: Total Quality Management (TQM).

Just at the middle of the nineteen's appeared a new family of norms (ISO 14000) related to the environmental management. It was the instrument that drove the increasing interest about environmental aspects. The ISO 14000 phenomenon is also being quite successful.

Recently, some specialized authors from the quality management area have formulated the hypothesis that ISO 900 norms could follow a logistic type growth pattern (Franceschini *et al*, 2004). This pattern is characterized by a slow beginning, followed by a high growth and afterwards there is a deceleration. At last, the saturation level is reached, when the number of certificates doesn't grow any farther. On the other hand, other researchers have suggested that there could be a relationship between ISO 9000 and ISO 14000 growth pattern (e.g.: Corbett and Kirsch, 2001).

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2.- Objective.

This article presents two versions of the model that generates the logistic curve. The first one is a simple *Excel* spreadsheet. The second one is written in *PSPS* language *–Programa Simulador de Pequeños Sistemas*-.

The behaviours of the two versions will be compared to the analytic equation logistic curve. So, there will be validated both versions. At the same time, the construction process allows to understand deeply the nature of the s-shaped curve.

3.- ISO 9000 and ISO 14000 standards.

Before analysing the diffusion of ISO 9000 and ISO 14000 standards, we think it is interesting to clarify an important question that frequently leads to some confusion: the ISO 9000 standards aren't norms to measure the quality of the products or services of a company. So, there aren't norms that lead to the fulfilment of a result, but there are norms that establish the necessity of systematising and formalizing a set of management processes. The fulfilment of the ISO 9000 indicates that the certificated company uses standardised proceedings and documents to produce the product or service bought by the client. Summarizing, this management tool lies on the systematisation of activities in order to obtain uniformity in the product and conformity in the fulfilment of the specifications established by the client (Anderson *et al*. 1999). We understand that this point should be clarified because there are some misunderstands about it.

It has to be pointed out that ISO 14000 establishes a reference model to implement a system in environmental management defined as the part of the global system that describes the organized structure, the planning activities, the responsibilities, the practices, the proceedings, the processes and resources to elaborate, apply, assess and maintain the environmental policy in the company. The ISO 14000 norms were published in September 1996 (although some companies had been certificated before according a previous draft). Here, it's also pertinent some analogous considerations of those we made about the ISO 9000. The ISO 14000, whose structure is quite similar to ISO 9000's, isn't a norm to measure the environmental impact caused by that implementation of the norm, but there is a set of norms to systematize and formalize the proceedings related to the environmental processes. Therefore, it isn't a norm of performance, but of proceedings. In this sense, we could affirm that the main difference between the two norms is that ISO 14000 establish, although in a weak and ambiguous way, a reference of the fulfilment of environmental objectives, because the norm establish that the company must compromises (*commitment*) to fulfil the norms and environmental regulations of each place. The European norm EMAS, more rigorous, establishes the necessity of accept (*compliance*) these norms and regulations.

As it has been said, the diffusion of both standards has been very successful, specially the ISO 9000. The last data provided by ISO (ISO, 2003) shows that in December of 2002 there already were 159 countries with companies certificated in ISO 9000 norm, and the number at worldwide scale was 561.747. In the moment that ISO 14000 was published, there were already 127.349 companies certificated in ISO 9000. As it was in the diffusion of ISO 9000, the ISO 14000 has been diffused as well all over the world, although less successfully. The last available data, that also corresponds to December 2002 (ISO , 2003), shows there already were 49.462 certificates in 118 countries.

3.- The logistic curve.

The mathematical literature shows that the logistic curve model was applied first time by the Belgian mathematic Verhulst in the XIX century. He used this pattern to explain the growth of specie. According to this model, the maximum growth is at the beginning, when there are few individuals competing for limited resources, and it tends to zero when the population reaches a certain size. This size is the saturation: number of individuals that can survive with the available resources.

The next causal diagram shows the phenomena.

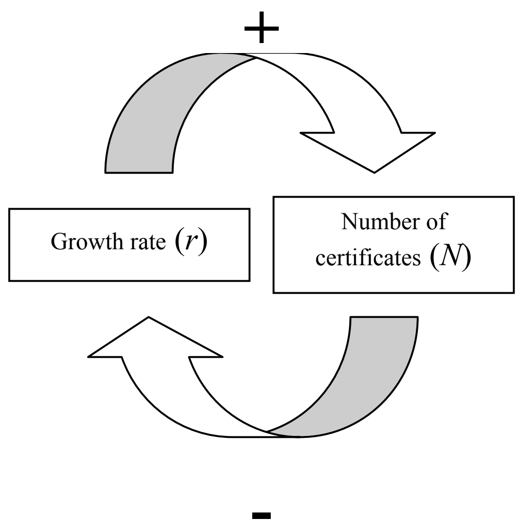


Figure 1: Causal Diagram of the variables that generate de logistic curve.

It can be observed that while the population size causes a decrease in the growth rate, the growth rate decreases when the population increases.

The model responds to the next expression:

$$N = \frac{N_0 K}{(K - N_0)e^{-r_0 t} + N_0}$$

where N is the number of certifications over time, N_0 represents the initial number of certificates, K is the maximum level that can be attained -saturation level-, while the initial growth rate is determined by r_0. In the annexes 1 and 2 are shown the equations that allow reaching this expression.

A regression was performed on the available of both historical data (ISO 9000 and ISO 14000), in order to adjust the logistic curve. The results are attached in annex 3. Annex 4 shows the graphics of both regressions, including the observed data.

4.- The model of the logistic curve expressed in an *Excel* spreadsheet.

The logistic curve is based on the expressions (1) and (2) of the annex 1. The expression (1) could be written as:

$dN = rNdt$ or also $N(t+dt) - N(t) = rNdt$ or $N(t+dt) = N(t) + rNdt$

N can be calculated at the moment after *t* as,

$N_{t+1} = N_t + r_t N_t dt$ or as well, $N_t = N_{t-1} + r_{t-1} N_{t-1} dt$ *(a)*, expression that may be represented in an easy way in a cell of an *Excel* spreadsheet, and extend the formula to a column. This way to solve the differential equation is the Euler's method (Riverola and Cuadrado, 2003). In the *excel* sheet, each row represents an instant of time. Therefore in each row there has to be calculated the variables time (*t*), the growth rate (*r*) and the number of certificates (*N*). There has been defined a time increase (*dt*) between two consecutives rows as a tenth part of a year. In order to calculate *N* at one instant, previously there has to be calculated the growth rate corresponding to the previous instant (r_{t-1}). This rate is calculated by the expression (2) of the annex 1. To complete the model, there has to be particularized the initial value of *N*, that as it has been said is represented as N_0. From here on, the model generates the *N* value over the time.

5.- Model of the logistic curve written in *PSPS* language.

Riverola and Cuadrado (2003) distinguish two kinds of simulation software: the *Languages of Simulation* and the *Special Purpose Simulators* (*SPS*). These latter are easier to manage, but its application area use to be limited: they are useful to some specific kind of problem. The *SPS* can be classified in four categories.

The first category of *SPS* software considers the reality as a set of levels in continual evolution over time. The systems they simulate use to be well defined through differential equations. The second category of *SPS* software is in the opposite pole. The changes in these systems don't occur in a continuous way, but in specific moments. The *PSPS* belongs to this category.

Before modelling the logistic curve using the *PSPS* simulator, we consider interesting to make a brief historic review that will allow introducing this software. William Sharpe, Nobel Prize and professor at Stanford University, was the forerunner of *PSPS*. He developed the first prototype and gave it to IESE. The further evolution of *PSPS* from there on was due to a group of IESE's professors, whose leaders were Josep Riverla and Jaume Ribera.

Although as it has been said, the natural environment of *PSPS* isn't the Dynamic Systems, nevertheless PSPS has a block[2] to implement Dynamic Systems: the INTEGRATE block. The block integrates a function using the Euler's method. It has been used as well a *dt* equivalent to a tenth of a year. The function that is integrated is defined in the next way in *PSPS* language:

[2] The basic elements of the PSPS language are named blocks.

```
NumberCertificates: function()
begin
        Return N = N + Growth*N*dt
        Return False
end;
```

The nucleolus of the function is the expression (a) of the last section. As it can be observed, the function calls to another auxiliary function that calculates the growth rate. In *PSPS*, this auxiliary function is expressed as follow:

```
Growth: function()
begin
        return InitialGrowth*(1-(N/Saturation))
end;
```

Obviously, there has previously been defined the parameters *InitialGrowth* and *Saturation*.

6.- Comparison of the results obtained through the software *Excel* and *PSPS* to explain the evolution of ISO 9000 and ISO 14000 certificates worldwide.

Table 1 shows the comparison of results obtained analyzing the evolution of ISO 9000 certificates.

Year	Observed data	Analytical equation	Excel	PSPS
1992	27.816	43.102	43.103	44.611
1993	54.502	60.922	60.890	62.667
1994	86.866	85.297	85.211	87.232
1995	127.349	117.906	117.740	119.944
1996	162.701	160.253	159.983	162.276
1997	223.299	213.174	212.786	215.068
1998	271.847	276.228	275.727	277.926
1999	343.643	347.217	346.637	348.748
2000	408.631	422.220	421.618	423.702
2001	510.616	496.327	495.768	497.908
2002	561.747	564.856	564.391	566.630

All data are on 31th December.
The data related to years 1993 and 1994 have been interpolated.

Table 1: Observed data of ISO 9000 certificates; generated values by the analytical equation of the logistic curve; results obtained through the two versions of the model (*Excel* and *PSPS*).

First of all, it has been analyzed the behaviour of the model comparing with the observed data. In order to do this, some T tests for two related samples have been performed. One of them compares the observed data to the results of the equation of the logistical curve. Another one analyzes the observed data to the *Excel* results. The third one is between the observed data and the *PSPS* results. The correlations are all high (,999) at ,000 significant level (see table 2).

	N	Correlation	Sig.
ISO 9000 certificates and logistic equation	11	,999	,000
ISO 9000 certificates and *Excel*	11	,999	,000
ISO 9000 certificates and *PSPS*	11	,999	,000
ISO 14000 certificates and logistic equation	8	1,000	,000
ISO 14000 certificates and *Excel*	8	1,000	,000
ISO 14000 certificates and *PSPS*	8	1,000	,000

Table 2: T tests for two related samples. Correlations of related samples.

In second place it has been performed an analogous analysis related to the ISO 14000 data. Table 3 shows the results obtained. We may see in table 2 that the correlations are also high.

Year	Observed data	Analytical equation	Excel	PSPS
1995	257	1.013	1.013	1.083
1996	1.491	2.013	2.008	2.104
1997	4.433	3.949	3.932	4.038
1998	7.887	7.561	7.516	7.584
1999	14.106	13.853	13.757	13.694
2000	22.897	23.612	23.452	23.173
2001	36.765	36.317	36.118	35.683
2002	49.462	49.561	49.381	49.012
All data are on 31th December.				

Table 3: Observed data of ISO 14000 certificates; generated values by the analytical equation of the logistic curve; results obtained through the two versions of the model (*Excel* and *PSPS*).

7.- Conclusions.

In this article we have shown how the worldwide diffusion of the ISO 14000 standard is taking place in much the same way as that of the ISO 9000 standard. The ISO 9000 standard, which is much older and more popular, is currently at 68.7% of saturation. It is estimated that it will reach 95% of saturation around the year 2008. The ISO 14000 standard, which was first introduced several years later, is being adopted at a much master speed, and will reach 95% of its saturation level in 2006.

From an operative point of view, it should be stressed that the two versions of the model of the logistic curve satisfactorily explain the historical evolution of the ISO 9000 and ISO 14000 certifications on a world scale.

We also want to point out that a simulator orientated to discreet systems, like PSPS, may have a good behaviour in dynamic environment. The results obtained indeed are close to the analytical expression of the logistic curve. The simulator is capable to describe a simple dynamic system as the analyzed.

ANNEX 1. The logistic curve.

The model describes the evolution of the population size that increases with a growth rate r (Boyee y Di Prima, 1992). It was formulated by Pierre Verhulst (1938) to analyze the growing of the biomass of specific specie.

$$\frac{dN}{dt} = rN \quad (1)$$

From an initial size (*N_0*), the population increases at growth rate *r*, which depends on the population size, following the expression:

$$r = r_0\left(1 - \frac{N}{K}\right) \quad (2)$$

The population grows at maximum level (*r_0*) when the population size is near zero. K value is the saturation size. When the population reaches this size, it doesn't grow any more. So, the growing may be written as:

$$\frac{dN}{dt} = r_0\left(1 - \frac{N}{K}\right)N = r_0 N - \frac{r_0}{K}N^2 \quad (3)$$

It is a differential equation of Bernouilli, whose generic expression is:

$$y' = a(x)y + b(x)y^n \quad (4)$$

and is solved by the variable change $y^{-n+1} = u$, and it is transformed into a lineal differential equation. In our case, the variable change is $N^{-2+1} = u$; or $N^{-1} = u$; or $N = u^{-1}$,so $N' = -\frac{u'}{u^2}$.

Appling the change in (3) we get the expression

$$-\frac{u'}{u^2} = r_0\frac{1}{u} - \frac{r_0}{k}\frac{1}{u^2} \quad (5)$$

that may be written as

$$u' = -r_0 u + \frac{r_0}{k} \quad (6)$$

This is a lineal differential equation.

In the other hand, a lineal differential equation like

$$y' = a(x)y + b(x) \quad (7)$$

has a solution:

$$y = e^{\int_0^x a(x)dx}\left[C + \int_0^x b(x)e^{-\int_0^x a(x)dx}dx\right] \quad (8)$$

In annex 2 another growing model is developed. There is solved an equation like (6). There is presented its resolution that applied to our case we get the solution:

$$u = \left(u_0 - \frac{r_0}{Kr_0}\right)e^{-r_0 t} + \frac{r_0}{k}\frac{1}{r_0} = (u_0 - \frac{1}{K})e^{-r_0 t} + \frac{1}{K} \quad (9)$$

Undoing the change of variable,

$$\frac{1}{N} = \left(\frac{1}{N_0} - \frac{1}{K}\right)e^{-r_0 t} + \frac{1}{K} \quad (10) \text{ so, } N = \frac{1}{\left(\frac{1}{N_0} - \frac{1}{K}\right)e^{-r_0 t} + \frac{1}{K}} \quad (11)$$

Other way to write the same expression is:

$$N = \frac{N_0 K}{(K - N_0)e^{-r_0 t} + N_0} \quad (12)$$

ANNEX 2

When the growing of a population is proportional to the size of the population, and besides there is another factor (constant over the time) that also affects this growing, this growing may be expressed as:

$$\frac{dN}{dt} = \alpha N + \beta \quad (13)$$

Is a lineal differential equation as (7), whose solution is presented in (8). In this case, the parameters are two constants:

$$a(x) = \alpha$$
$$b(x) = \beta$$

Particularising the expression (8) we obtain:

$$N = e^{\int_0^t \alpha dt}\left[C + \int_0^t \beta e^{-\int_0^t \alpha dt} dt\right] = e^{\alpha[t]_0^t}\left[C + \beta\int_0^t e^{-\alpha[t]_0^t} dt\right] = e^{\alpha t}\left[C + \beta\int_0^t e^{-\alpha t} dt\right]$$

$$N = e^{\alpha t}\left[C + \beta\left(-\frac{1}{\alpha}\right)\left[e^{-\alpha t}\right]_0^t\right] = e^{\alpha t}\left[C - \frac{\beta}{\alpha}\left(e^{-\alpha t} - 1\right)\right] = e^{\alpha t}\left(C + \frac{\beta}{\alpha}\right) - \frac{\beta}{\alpha} \quad (14)$$

In order to get the C constant, we particularize to the initial instant (t=0).

$$N_0 = N(t = 0) = \left(C + \frac{\beta}{\alpha}\right) - \frac{\beta}{\alpha} = C \quad (15)$$

therefore, the expression (15) is transformed into:

$$N = \left(N_0 + \frac{\beta}{\alpha}\right)e^{\alpha t} - \frac{\beta}{\alpha} \quad (16)$$

that indeed is solution of (13), because the derivate of the expression (16) is

$$\frac{dN}{dt} = \left(N_0 + \frac{\beta}{\alpha}\right)\alpha e^{\alpha t} \quad (17)$$

and for other hand,

$$\alpha N + \beta = \alpha\left[\left(N_0 + \frac{\beta}{\alpha}\right)e^{\alpha t} - \frac{\beta}{\alpha}\right] + \beta = \left(N_0 + \frac{\beta}{\alpha}\right)\alpha e^{\alpha t} \quad (18)$$

as we wanted demonstrated.

ANNEX 3. ISO 9000 and ISO 14000 regressions applying a logistic curve model.

ISO 9000 certificates worldwide regression (1) (2).

Dependent Variable: ISO 9000 worldwide certificates

Source	DF	Sum of squares	Mean square
Regression	3	1038195251858	346065083953
Residual	8	905463045,266	113182880,658
Uncorrected Total	11	1039100714903	
(corrected total)	10	337015670695	

R squared = 1 - Residual SS / Corrected SS = ,99731

Parameter	Value	Asymptotic Std. Error	Asymptotic 95 % Confidence Interval Lower	Upper
N_0	43102,8528	4201,0725	33415,1622	52790,5434
K	817539,0186	67398,7551	662117,2107	972960,8266
r_0	,3693	,02372	,3146	,4240

ISO 14000 certificates worldwide (1).

Dependent Variable: ISO 14000 worldwide certificates

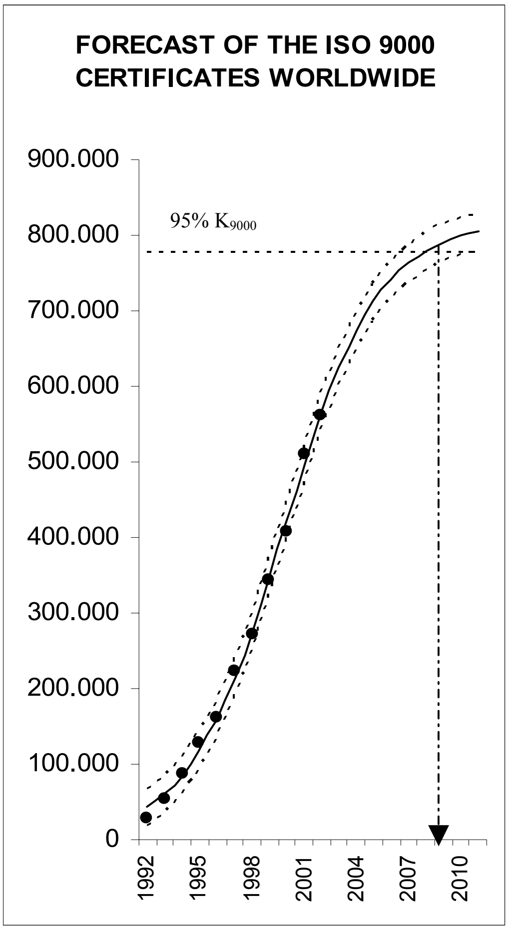
Source	DF	Sum of squares	Mean square
Regression	3	4603582247,41	1534527415,80
Residual	8	1969654,5888	393930,9178
Uncorrected Total	5	4605551902,00	
(corrected total)	7	2249209301,50	

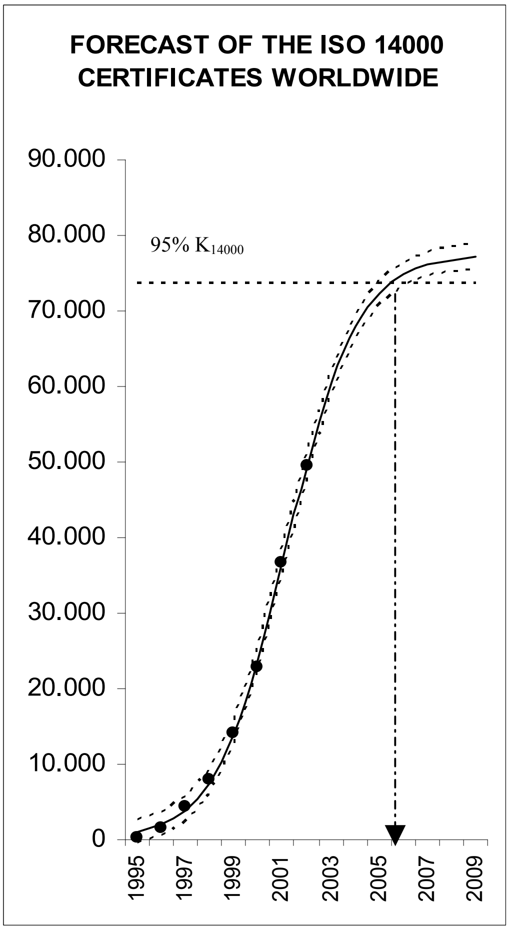
R squared = 1 - Residual SS / Corrected SS = ,9991

Parameter	Value	Asymptotic Std. Error	Asymptotic 95 % Confidence Interval Lower	Upper
N_0	1013,1052	150,5268	626,1636	1400,0467
K	77416,9573	5922,3611	62193,0435	92640,8711
r_0	,6999	,03719	,6043	,7955

(1) Data are of December 31th of each year.
(2) Data related to years 1993 and 1994 have been interpolated.

ANNEX 4. ISO 9000 and ISO 14000 forecasts at worldwide scale.





The figures highlight the empirical data (black points), the fit curve (continuous line) and the forecast confidence interval (95 per cent) (discontinues lines). It can be observed that the 95% of the saturation will be reached in 2008 for ISO 9000 and in 2006 for ISO 14000.

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