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Inventory Management, Spare Parts and Reliability Centred Maintenance for Production Lines

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1. Introduction

1st Premise: Ever since he was a young student, at the secondary school, Fausto Galetto was fond of understanding the matters he was studying: ***understanding for learning*** was his credo (φιλομαθης συνιημι); for all his life he was keeping this attitude, studying more than one ton of pages: as manager and as consultant he studied several methods invented by professors, but never he used the (many) wrong ones; on the contrary, he has been devising many original methods needed for solving the problems of the Companies he worked for, and presenting them at international conferences [where he met many bad divulgers, also *professors "ASQC* ***certified*** *quality auditors"*]; after 25 years of applications and experience, he became professor, with a dream "improve future managers (students) quality": the incompetents he met since then grew dramatically (also with documents. F.Galetto got from students ERASMUS, (Fijiu Antony et al., 2001, Sarin S. 1997). 2nd Premise: *"The wealth of nations depends increasingly on the quality of managers."* (A. Jay) and "Universities grow future managers." (F. Galetto) Entailment: due to that, the author with this paper will try, again, to provide the important consequent message: *let's, all of us, be scientific in all Universities*, that is, *let's all use our rationality*. *"What I want to teach is: to pass from a hidden non-sense to a non-sense clear."* (L. Wittgenstein). END [see the Galetto references]
"In my university studies …, in most of the cases, it seemed that students were asked simply to regurgitate at the exams what they had swallowed during the courses." (M. Gell-Mann "The Quark and the Jaguar..." [1994]). Some of those students later could have become researchers and then professors, writing "scientific" papers and books … For these last, another statement of the Nobel Prize M. Gell-Mann is relevant: *"Once that such a misunderstanding has taken place in the publication, it tends to become perpetual, because the various authors simply copy one each other."*...., similar to "Imitatores, servum pecus" [Horatius, 18 B.C.!!] and "Gravior et validior est decem virorum bonorum sententia quam totius multitudinis imperitiae" [Cicero]. When they teach, "***The result is that hundreds of people are learning what is wrong. I make this statement on the basis of experience, seeing every day the devastating effects of incompetent teaching and faulty applications.*** [Deming (1986)]**"**, because those professors are unable to practice maieutics [μαιευτικη τεχνη], the way used by Socrates for teaching [the same was for Galileo Galilei in the *Dialogue on the Two Chief World Systems*]. Paraphrasing P. B. Crosby,

in his book Quality is free, we could say "Professors may or may not realize what has to be done to achieve quality. Or worse, they may feel, mistakenly, that they do understand what has to be done. Those types can cause the most harm."

What do have in common Crosby, Deming and Gell-Mann statements? The fact that professors and students betray an important characteristic of human beings: rationality [the "Adult state" of E. Berne (see fig. 1)]. Human beings are driven by curiosity that demands that we ask questions ("why?. …, why?") and we try to put things in order ("this is connected with that"): curiosity is one of the best ways to learn, but "learning does not mean understanding"; only twenty-six centuries ago, in Greece, people began to have the idea that the "world" could be "understood rationally", overcoming the religious myths: they were sceptic [σκεπτομαι=to observe, to investigate] and critic [κρινω=to judge]: then and there a new kind of knowledge arose, the "rational knowledge".

Till today, after so long time, we still do not use appropriately our brain! A peculiar, stupid and terrific non-sense! During his deep and long experience of Managing and Teaching (more than 40 years), F. Galetto always had the opportunity of verifying the truth of Crosby, Deming and Gell-Mann statements.

Before proceeding we need to define the word "scientific".

A document (paper or book) is "scientific" if it "scientifically (i.e. with "scientific method") deals with matters concerning science (or science principles, or science rules)". Therefore to be "scientific" a paper must both concern "science matters" and be in accordance with the "scientific method".

The word "science" is derived from the Latin word "scire" (to know for certain) {derived from the Greek words μαθησις, επιστημη, meaning learning and knowledge, which, at that time, were very superior to "opinion" [δοξα], while today opinion of many is considered better than the knowledge of very few!}; knowledge is strongly related to "logic reasoning" [λογικος νους], as it was, for ages, for Euclid, whose Geometry was considered the best model of "scientificness". Common (good) sense ***is not*** science! Common sense does not look for "understanding", while science looks for "understanding"! "Understanding" is related to "intelligence" (from the Latin verb "intelligere" ([intus+legere: read into]: "intellige ut credas" i.e. understand to believe. Unfortunately "*none so deaf as those that won't hear*".

Let's give an example, the Pythagoras Theorem: *In a right triangle, the square of the length of the hypotenuse equals the sum of the squares of the lengths of the other two sides*. Is this statement scientific? It could be scientific because it concerns the science of Geometry and it can be proven true by mathematical arguments. It is not-scientific because we did not specify that we were dealing with the "Euclidean Geometry" (based, among others, on the "parallel axiom": from this only, one can derive that the sum of the interior angles of a triangle is always π): we did not deal "scientifically" with the axioms; we assumed them implicitly.

So we see that "scientificness" is present only if the set of statements (concerning a given "system") are non-contradictory and deductible from stated principles (as the rules of Logic and the Axioms).

Let's give another example, the 2nd law of Mechanics: *The force and the acceleration of a body are proportional vectors:* $\boldsymbol{F}=m\boldsymbol{a}$, *(m is the mass of the body)*. Is this statement scientific? It could be scientific because it concerns the science of Mechanics and it can be proven "true" by well designed experiments. It is not-scientific because we did not specify that we were dealing with "frames of reference moving relatively one to another with constant velocity" [inertial frames (with the so called "Galilean Relativity": the laws of Physics look the same for inertial systems)] and that the speed involved was not comparable with the "speed of light in the vacuum [that is the same for all observers]" (as proved by the Michelson-Morley experiment: in the Special Relativity Theory, **F**=d(m**v**)/dt is true, not **F**=m**a**!) and not involving atomic or subatomic particles. We did not deal "scientifically" with the hypotheses; we assumed them implicitly. From the laws of Special Relativity we can derive *logically* the conservation laws of momentum and of energy, as could Newton for the "Galilean Relativity". For atomic or subatomic particles "quantum Mechanics" is needed (with Schrödinger equation as fundamental law).

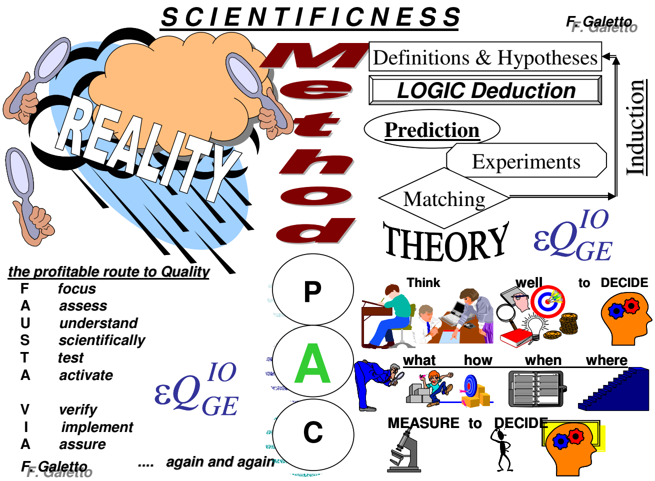


Fig. 1. Scientificness

So we see that "scientificness" is present **only** if the set of statements (concerning a given "system") do not contradict the observed data, collected through well designed experiments ["scientific" experiments]: only in the XVII century, due to Galilei, Descartes, Newton, … we learned that. Since that time only, science could really grow.

When we start trying to learn something, generally, we are in the "clouds"; reality (and truth) is hidden by the clouds of our ignorance, the clouds of the data, the clouds of our misconceptions, the clouds of our prejudices; to understand the phenomena we need to find out the reality from the clouds: we make hypotheses, then we deduct logically some consequences, predicting the results of experiments: if predictions and experimental data do match then we "confirm" our idea and if many other are able to check our findings we get a theory. To generate a theory we need Methods. Eric Berne, the psychologist father of "Transactional Analysis", stated that everybody interacts with other people trough three states P, A, C [Parent, Adult, Child, (not connected with our age, fig. 1)]: the Adult state is the one that looks for reality, makes questions, considers the data, analyses objectively the data, draws conclusions and takes logic decisions, coherent with the data, methodically. Theory [θεωρια] comes from the Adult state! Methods [μεθοδος from μετα+οδος = the way through (which one finds out…)] used to generate a Theory come from the Adult state!

People who take for granted that the truth depends on "Ipse dixit" [αυτος εφα, "he said that"], behave with the Parent state. People who get upset if one finds their errors and they do not consider them ["we are many and so we are right", they say!!] behave with the Child state. [see the books of the Palo Alto group]

To find scientifically the truth (out of the clouds) you must **F**ocus on the problem, **A**ssess where you are (with previous data and knowledge), **U**nderstand **S**cientifically the message in the data and find consequences that confirm (or disprove) your predictions, Scientifically design **T**est for confirmation (or disproval) and then **A**ctivate to make the Tests. If you and others **V**erify you prediction, anybody can **I**mplement actions and **A**ssure that the results are SCIENTIFIC (FAUSTA VIA): all of us then have a THEORY. SCIENTIFICNESS is there (fig. 1).

From these two examples it is important to realise that when two people want to verbally communicate, they must have some common concepts, they agree upon, in order to transfer information and ideas between each other; this is a prerequisite, if they want to understand each other: what is true for them, what is their "conventional" meaning of the words they use, which are the rules to deduce statements (Theses) from other statements (Hypotheses and "previous" Theses): **rigour** is needed for **science**, not opinions!!!

Many people must apply *Metanoia* [μετανοια=change their mind (to understand)] to find the truth.

Here we accept the rules of LOGIC, the *deductive* logic, where the premises of a valid argument contain the conclusion, and the truth of the conclusion follows from the truth of the premises with certainty: any well-formed sentence is either true or false. We define as *Theorem* "a statement that is proven true by reasoning, according to the rules of Logic"; we must therefore define the term *True*: "something" (statement, concept, idea, sentence, proposition) is true when there is *correspondence* between the "something" and the facts, situations or state of affairs that verify it; the *truth* is a relation of *coherence* between a thesis and the hypotheses. Logical validity is a relationship between the premises and the conclusion such that if the premises are true then the conclusion is true. The validity of an argument should be distinguished from the truth of the conclusion (based on the premises). This kind of truth is found in mathematics.

Human beings evolved because they were able to develop their knowledge from inside (the *deductive* logic, with analytic statements) and from outside, the external world, (the *inductive* logic, with synthetic statements), in any case using their intelligence; the *inductive* logic is such that the premises are evidence for the conclusion, but the truth of the conclusion follows from the truth of the evidence only with a certain probability, provided the way of reasoning is correct.

The scientific knowledge is such that any valid knowledge claim must be verifiable in experience and built up both through the *inductive* logic (with its synthetic statements) and the *deductive* logic (with its analytic statements); in any case a clear distinction must be maintained between analytic and synthetic statements.

This was the attitude of Galileo Galilei in his studies of falling bodies. At first time he formulated the tentative hypothesis that "the speed attained by a falling body is directly proportional to the distance traversed"; then he deduced from his hypothesis the conclusion that objects falling equal distances require the same amount of elapsed time. After "Gedanken Experimenten", Designed Experiments made clear that this was a false conclusion: hence, logically, the first hypothesis had to be false. Therefore Galileo framed a new hypothesis: "the speed attained is directly proportional to the time elapsed". From this he was able to deduce that the distance traversed by a falling object was proportional to the

square of the time elapsed; through Designed Experiments, by rolling balls down an inclined plane, he was able to verify experimentally his thesis (it was the first formulation of the 2nd law of Mechanics). [fig. 1]
Such agreement of a conclusion with an actual observation does not itself prove the correctness of the hypothesis from which the conclusion is derived. It simply renders that premise much more plausible.
For rational people (like were the ancient Greeks) the criticism [κρινω = to judge] is hoped for, because it permits improvement: asking questions, debating and looking for answers improves our understanding: we do not know the truth, but we can look for it and be able to find it, with our brain; to judge we need criteria [κριτεριον]. In this search Mathematics [note μαθησις] and Logic can help us a lot: Mathematics and Logic are the languages that Rational Managers must know! Proposing the criterion of testability, or falsificability, for scientific validity, Popper emphasized the *hypothetico-deductive character of science*. Scientific theories are hypotheses from which can be deduced statements testable by observation; if the appropriate experimental observations falsify these statements, the hypothesis is refused. If a hypothesis survives efforts to falsify it, it may be tentatively accepted. No scientific theory, however, can be conclusively established. A "theory" that is falsified, is **NOT** scientific.
"Good theories" are such that they **complete** previous "good" theories, in accordance with the collected new data. [fig. 1]
A good example of that is **Bell's Inequality**. In physics, this inequality was used to show that a class of theories that were intended to "complete" quantum mechanics, namely local hidden variable theories, are in fact inconsistent with quantum mechanics; quantum mechanics typically predicts probabilities, not certainties, for the outcomes of measurements. Albert Einstein [one of the greatest scientists] stated that quantum mechanics was incomplete, and that there must exist "hidden" variables that would make possible definite predictions. In 1964, J. S. Bell proved that all local hidden variable theories are inconsistent with quantum mechanics, first through a "Gedanken Experiment" and Logic, and later through Designed Experiments. Also the great scientist, A. Einstein, was wrong in this case: his idea was falsified. We see then that the ultimate test of the validity of a scientific hypothesis is its *consistency* with the totality of other aspects of the scientific framework. This inner consistency constitutes the basis for the concept of causality in science, according to which every effect is assumed to be linked with a cause. [fig. 1]
The scientific community as a whole must judge [κρινω] the work of its members by the ***objectivity and rigour*** with which that work has been conducted; in this way the scientific method should prevail.
In any case the scientific community must remember: ***Any statement (or method) that is falsified, is NOT scientific.***
Here we assume that the subject of a paper is concerning a science (like Mathematics, Statistics, Probability, Quality Methods); therefore to judge [κρινω] if a paper is scientific we have to look at the "scientific method": if the "scientific method" is present, i.e. the conclusions (statements) in the paper follow logically from the hypotheses, we shall consider the paper scientific; **on the contrary**, if there are conclusions (statements) in the paper that do not follow logically from the hypotheses, we shall NOT consider the paper scientific: a ***wrong conclusion (statement) is NOT scientific***. [fig. 1 vs Franceschini 1999]
"*To understand that an answer is wrong you don't need exceptional intelligence, but to understand that is wrong a question one needs a creative mind.*" (A. Jay). "Intellige ut credas".

Right questions, with right methods, have to be asked to "nature" (fig. 1). "Intellige ut credas".
It is easy to show that a paper, a book, a method, is not scientific: it is sufficient to find an example that proves the wrongness of the conclusion. When there are formulas in a paper, it is not necessary to find the right formula to prove that a formula is wrong: an example is enough; to prove that a formula is wrong, one needs only intelligence; on the contrary, to find the right formula, that substitutes the wrong one, you need both intelligence and ingenuity. I will use only intelligence and I will not give any proof of my ingenuity: this paper is for intelligence … For example, it's well known (from Algebra, Newton identities) that the coefficients and the roots of any algebraic equation are related: it's easy to prove that $\pm\sqrt{-c/a}$ is not the solution (even if you do not know the right solution) of the parabolic equation $ax^2+bx+c=0$, because the system $x_1+x_2=-b/a$, $x_1x_2=c/a$ is not satisfied (x_1 and x_2 are the roots). [Montgomery 1996 and ....]
The literature on "Quality" matters is rapidly expanding. Unfortunately, nobody, but me, as far as I know, [I thank any person that will send me names of people who take care …], takes care of the ***Quality of Quality Methods used for making Quality*** (of product, processes and services). "Intellige ut credas". [O' Connor 1997, Brandimarte 2004]
I am eager to meet one of them, fond of Quality as I am. [fig. 1, and Galetto references]
If this kind of person existed, he would have agreed that "***facts and figures are useless, if not dangerous, without a sound theory***" (F. Galetto), "**Management need to grow-up their knowledge because experience alone, without theory, teaches nothing what to do to make Quality**" (Deming) because he had seen, like Deming, Gell-Mann and myself "***The result is that hundreds of people are learning what is wrong. I make this statement on the basis of experience, seeing every day the devastating effects of incompetent teaching and faulty applications.***" [Deming (1986)] (Montgomery 1996 and ...., Franceschini 1999)
During 2006 F. Galetto experienced the incompetence of several people who were thinking that only the "Peer Review Process" is able to assure the scientificness of papers, and that only papers published in some magazines are scientific: one is a scientist and gets funds if he publishes on those magazines!!! Using the scientific method one can prove that the referee analysis does not assure quality of publications in the magazines of fig. 2.

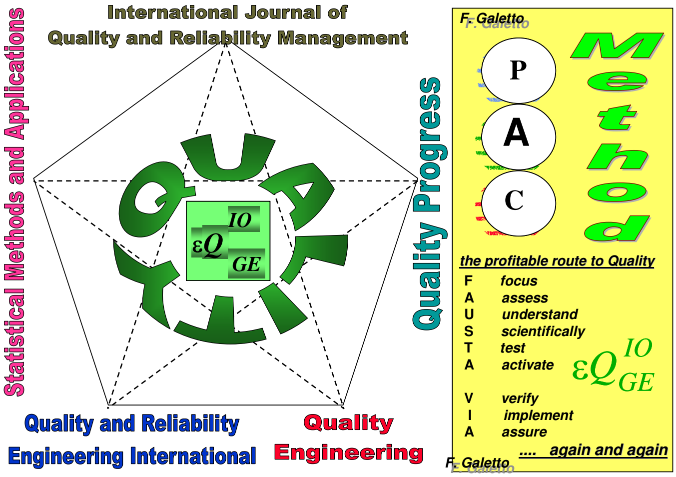


Fig. 2. The "pentalogy"

The symbol εQ_{GE}^{IO} [which stands for the "***epsilon Quality***"] was devised by F. Galetto to show that ***Q***uality depends, at any instant, in any place, at any rate of improvement, on the ***I***ntellectual h***O***nesty of people who always use experiments and think well on the experiments before actually making them (***G***edanken ***E***xperimenten) to find the truth" [*Gedanken Experimenten* was a statement used by Einstein; but, if you look at Galileo life, you can see that also the Italian scientist was used to "mental experiments", the most important tool for Science; Epsilon (ε) is a greek letter used in Mathematics and Engineering to indicate a very small quantity (actually going to zero); ***epsilon Quality*** conveys the idea that Quality is made of many and many prevention and improvement actions].
The level of knowledge F. Galetto could verify (in 40 years experience and a lot of meetings) is given in table 1.

	Logic	Management	Mathematics	Physics	Quality Management	Probability	Stochastic Processes	Statistics	Applied Statistical Methods	Parameter Estimation	Test of Hypotheses	Decision Making	System Reliability Theory	Maintainability	Design Of Experiments	Control Charts	Sampling Plans	Quality Engineering	Quality Practice
Professors	1 H	VL 95	VL 98	VL 98	VL 99	VL 99	VL 99	VL 99	VL 99	VL 99	VL 99	VL 95	VL 99	VL 99	VL 99	VL 99	VL 99	VL 99	VL 99
Managers	VL 95	VL 95	VL 98	VL 98	VL 99	VL 99	VL 99	VL 99	VL 99	VL 99	VL 99	VL 95	VL 99	VL 99	VL 99	VL 99	VL 99	1 VH	1 VH
Consultants	VL 99	VL 95	VL 98	VL 98	VL 99	VL 99	VL 99	VL 99	VL 99	VL 99	VL 99	VL 95	VL 99	VL 99	VL 99	VL 99	VL 99	1 VH	1 VH

Legenda : VL90=probability 90% that knowledge is lower than Very Low;
5VH=probability 5% that knowledge is higher than Very High
Scale: None, Very Low, Low, Medium, High, Very High, Perfect

Table 1. Level of Knowledge (based on 40 year of experience, in companies and universities)

Many times F. Galetto spoiled his time and enthusiasm at conferences, in University and in Company courses, trying to provide good ideas on Quality and showing many cases of wrong applications of stupid methods [see references]. He will try to do it again … by showing, step by step, very few cases (out of the hundreds he could document).... in order people understand that QUALITY is a serious matter. The Nobel price R. Feynman (1965) said that *for the progress of Science are necessary experimental capability, honesty in providing the results and the intelligence of interpreting them… We need to take into account of the experiments **even though** the results are different from our expectations*. It is apparent that Deming and Feynman and Gell-Mann are in agreement with εQ_{GE}^{IO} ideas of F. Galetto. Once upon a time, A. Einstein said "*Surely there are two things infinite in the world: the Universe and the Stupidity of people. But I have some doubt that Universe is infinite*". Let's hope that Einstein was wrong, this time. Anyway, before him, Galileo Galilei had said [in the *Saggiatore*] something similar "*Infinite is the mob of fools* ". [see references]

All the methods, devised by F. Galetto, were invented and have been used for preventing and solving real problems in the Companies he was working for, as Quality Manager and as Quality Consultant: several million € have been saved.[see Galetto references]
Companies will not be able to survive the global market if they cannot provide integrally their customer the Quality they have paid for [fig. 5, Management Tetrahedron]. So it is of paramount importance to define correctly what Quality means. Quality is a serious and difficult business; it has to become an integral part of management.
The first step is to define *logically* what Quality is.
Let's start with some ideas of Soren Bisgard (2005) given in the paper Innovation, ENBIS and the Importance of Practice in the Development of Statistics, *Quality and Reliability Engineering International*. He says: "*Since the early 1930s industrial statistics has been almost synonymous with quality control and quality improvement. Some of the most important innovations in statistical theory and methods have been associated with quality.*" …. "*Quality Management also provides an intriguing example. Its scientific underpinning is greatly inspired by statistics, a point forcefully set forth by Shewhart. Quality is typically interpreted narrowly by statisticians as variance and defect reduction. However these efforts should be viewed more broadly as what economist call **innovation**. When we engage in statistical quality control studies … we are engaged in **process innovation** and … in **product innovation**.*" Two paragraphs of his paper are entitled: 2. Quality as innovation, and 3. Quality as systematic innovation.
One must say that the paper does not provide the definition of the term Quality, such as "Quality is …"; however he realises that statisticians have a narrow view of Quality, as "Quality is *variance and defect reduction*."
As a matter of fact, D. C. Montgomery defines: "*Quality is the inverse of variability*" (saying "*We prefer a **modern** definition of quality*") and adds "*Quality Improvement is the reduction of variability in processes and products*". To understand the following subject the reader has to know Reliability and Statistics. Let's consider two computers (products A and B): after 3 years, A experiences $g_A(3)=9$ failures, while B experiences $g_B(3)=5$ failures; which product has better quality? B, because it experienced less failures! BUT, which product has lower variability? A, because it experienced more failures!
Generally, statisticians (and professors) do not understand this point: they are Gauss-drugged with the "normal distribution"! Let's assume, for the sake of simplicity, that two items have constant increasing failure rate (IFR, they do wear and do not have infant mortality); form the data we can estimate the MTTF (Mean Time To Failure), the Reliability R(t) and the probability density of failures f(t): B is more reliable and has more variability [the upper curve]! Therefore according to D. C. Montgomery definition B (that is more reliable) has lower "quality"! Fig 3 provides a hint for understanding ….

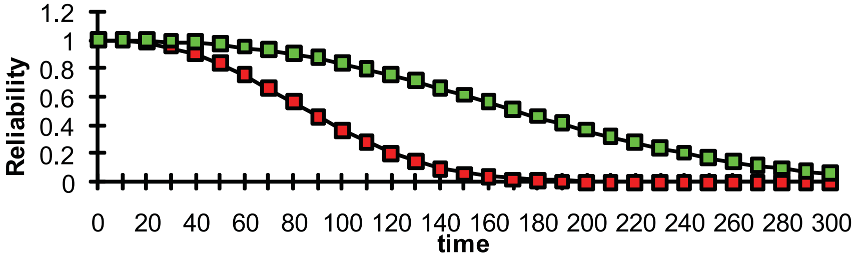


Fig. 3. An item with more variability B, has better Quality

If one thinks to the Formula One Championship and applies Montgomery's definition he finds that if the two Red Bull arrive 1st and 2nd they have lower quality than the two Ferrari that arrive 7th and 8th!!!!! Can you believe it?

There are a lot of "quality definitions; let's see some of the latest definitions of the word "Quality" that can be found in the literature (some of them existed before the date here given; the date shown refers to the latest document I read):

"conformance to requirements" (Crosby, 1979), "fitness for use" (Juran ,1988), "customer satisfaction" (Juran, 1993), "the total composite product and service characteristics of marketing, engineering, manufacture and maintenance through which product or service in use will meet the expectations by the customer" (Feigenbaum, 1983 and 1991)¸"totality of characteristics of an entity that bears on its ability to satisfy stated and implied needs" (ISO 8402:1994), "a predictable degree of uniformity and dependability at low cost and suited to the market" (***falsely*** *attributed to* Deming, 1986; I read again and again Deming documents and I could not find that), "Quality is inversely proportional to variability" (Montgomery, 1996), "degree to which a set of inherent characteristics (3.5.1) fulfils requirements (3.1.2)" [**ISO 9000:2000, Quality management systems – Fundamentals and vocabulary,** (definition 3.1.1)]

The ISO definition is very stupid; it is like confounding two very different concepts: energy and temperature; "temperature" provides the *degree* of "energy" [=Quality]; therefore *Quality* must be "the set of characteristics".

Quality definition must have Quality in it!

In order to provide a practical and managerial definition, since 1985 F. Galetto was proposing the following one:

Quality is the set of characteristics of a system that makes it able to satisfy the *needs* of the Customer, of the User and of the Society. It is clear that none of the previous eight definitions highlights the importance of the ***needs*** of the three actors: **the Customer, the User and the Society**. They are still not considered in the latest document, the ISO 9000:2008, Quality management systems – Fundamentals and vocabulary.

Some important characteristics are stated in the Quality Tetrahedron of ten characteristics Safety, Conformity, Reliability, Durability, Maintainability, Performance, Service, Aesthetics, Economy, Ecology; each characteristic has an "operational definition" that permits to state goals and verify achievement [according to FAUSTA VIA]. "Customer/User/Society ***needs*** satisfaction" must be converted from a slogan to real practice, if companies want to be competitive. Today, many managers show their commitment with customer satisfaction, but they are not prepared to invest time and money in NEEDS Satisfaction; they do not put the theory into practice; they do not speak with the facts, but only with words.

Unfortunately *management commitment to Quality is not enough*; managers must understand and learn Quality ideas: too many companies are well behind the desired level of Quality management practices. [fig. 5]

The Quality Tetrahedron shows that Management must learn that ***solving problems is essential but it is not enough***: **they must prevent future problems and take preventive actions**: Safety, Reliability, Durability, Maintainability, Ecology, Economy can be tackled rightly only through preventive actions; the PDCA cycle is useless for prevention; it very useful for improvement. Several of the Quality characteristics [in the Quality Tetrahedron] need prevention; reliability is one of the most important: very rarely failures can be attributed to blue collar workers. Failures arise from lack of prevention, and prevention is a fundamental aspect and responsibility of Management. The same happens for safety, durability, maintainability, ecology, economy, ...

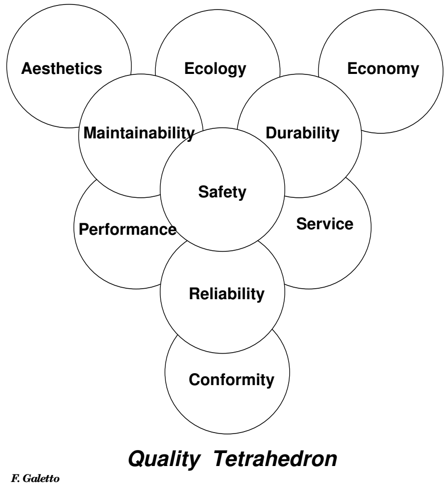


Fig. 4. The Quality Tetrahedron for the Quality definition

So we see that Quality entails much more than “innovation”: you can innovate without Quality! Few decades ago electronic gadgets entered into cars; electronics was an innovation in cars, but the cars failed a lot: innovation did not take into consideration ***prevention***! The essence of Quality is prevention. Innovation is a means for competition, rarely for Quality. (see the “Business Management System” in figure 5).

We are in a new economic age: long-term thinking, prevention, Quality built at the design stage, understanding variation, waste elimination, knowledge and scientific approach are concepts absolutely needed by Management , if they want to be good Managers. In this paper, Manager is the person who *achieves the Company goals, economically, through other people, recognise existing problems, prevents future problems, states priorities, dealing with their conflicts, makes decisions thinking to their consequences, with rational and scientific method, using thinking capability and knowledge of people.* These kind of Managers behave according to the “Business Management System”.

The customer is the most important driving force of any company. Companies will not be able to survive the global market if they cannot provide integrally their customer the Quality they have paid for. It is important to stress that “Customer Needs Satisfaction” is absolutely different from “Customer Satisfaction”. Moreover, the previous analysis show that for a good definition of Quality there are other people involved: the user and the Society.

Prevention... We said that the essence of Quality is prevention. Innovation is a means for competition, rarely for Quality. (see the “Business Management System”). Quality is essential for any product (services are defined as products in the ISO 9000:2000 terminology). The measurement of Quality (of product and services) is important if we want to improve and better if we want to prevent problems [F. Galetto from 1973]. Quality depends on effective management of problems prevention and correction (improvement). Effective management needs effective measurement of performance and results, the absolute condition to achieve Business Excellence. A Company that wants to become “excellent” has to find the needs of Customers/Users/Society and to measure how much they are achieved. Moreover that Company has to be “sure” that all its processes are “in

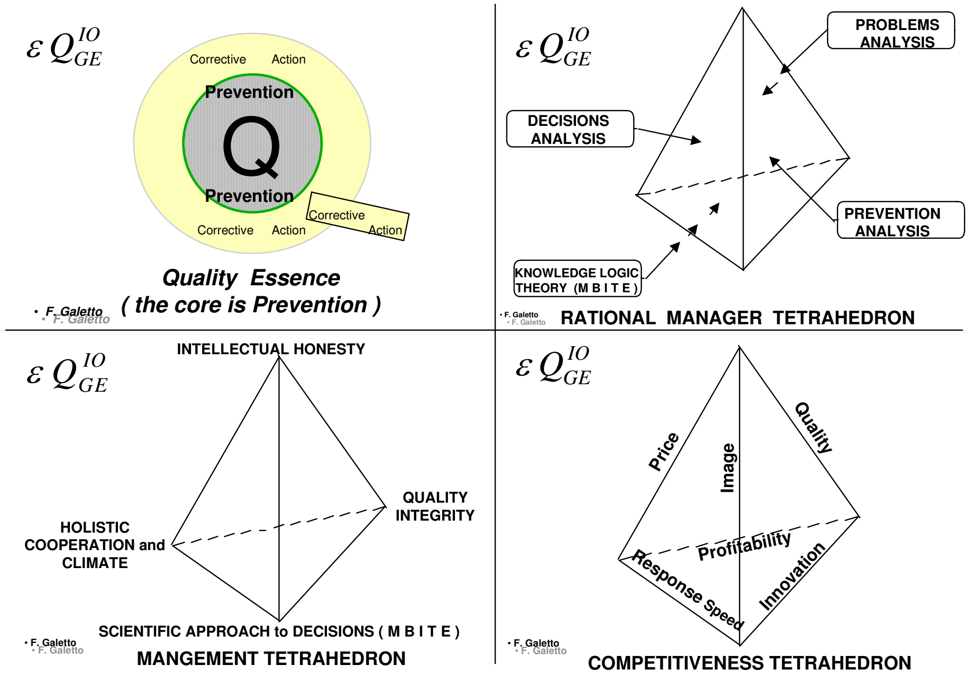


Fig. 5. The Business Management System

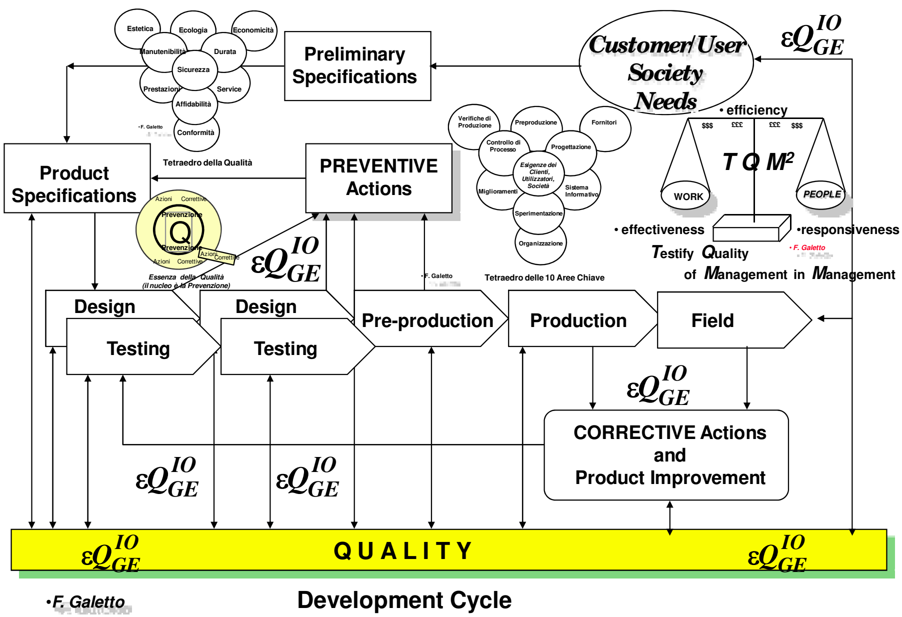


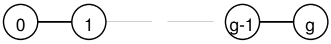
Fig. 6. The Development Cycle

control". If data are available (through properly designed method of collection), statistical methods are the foundation stone for good data analysis and "management decisions" [F. Galetto from 1973].

Prevention is very important and must be considered since from the first stages of product development as shown in figure 6; corrective actions come later.

Reliability is important in all the stages of product development. Reliability tests are essential during product development; collected data have to be analysed by scientific methods that involve Engineering, Statistics and Probability Methods. Reliability is important for preventive maintenance and for the so called RCM (Reliability Centred Maintenance). Let's for example consider the methods for data analyses and maintenance planning, as given in the papers "Total time on test plotting for failure data analyses", (1978), *SAAB-SCANIA*, and "Some graphical methods for maintenance planning", (1977), ***Reliability & Maintainability Symposium***. They are connected with similar ideas of Barlow.

Let' consider a sample made of n "identical" items (n=sample size), that are neither repaired nor replaced after failure. We can view the tested sample as a system ("in parallel") that can be represented as in the graph, where state "i" indicates that "i" items are failed; g indicates the last failure observed during the test. When g=n we can apply the TTT-plot.



At any time instant x, some of the n units can be still alive (survived up to time x), while the other are failed, before x; the sum of all the "survival times" of the n items put on test is denoted TTT(x) [and named the Total Time on Test, up to the time instant x]; the duration of the test depends on the failure of the last item (out of the n) that will fail. If the items fail at times t_1, t_2, …, t_n, then TTT(t_1) is the Total Time on Test until the 1st failure, TTT(t_i) is the Total Time on Test until the ith failure and TTT(t_n) is the Total Time on Test until the ith failure. If T_i is the *random variable* "Time to the ith failure" then TTT(T_i) is the *random variable* "Total Time on Test until the ith failure": the distribution of the *random variable* TTT(T_i) depends on the distribution of the *random variable* T_i, which depends on the distribution of the *random variable* T "Time to Failure" of any of the n "identical" items put on test. The n-1 *random variables* U_i=TTT(T_i)/TTT(T_n), the *scaled TTT*, have a distribution that depends on the *random variable* T "Time to Failure" of any item; since the distribution $F_T(t)$ of the r.v. T depends on the failure rate, one can plot a curve $F_U(t)$ [named TTT-transform] versus $F_T(t)$: the curve is contained in the square unit of the Cartesian plane and its shape depends on the type of the failure rate [constant, IFR (increasing), or DFR (decreasing)]. Therefore the TTT-plotting allows understanding the type of failure rate.

The evolution of the system depends from the functions $b_{i,i+1}(s|r)ds$, probability of the transition i⇒i+1 (i.e. the (i+1)th failure) in the interval s---s+ds, given that it happened into the state "i" at the time instant r; the functions $b_{i,i+1}(s|r)$ [named "kernel of the stochastic process" of failures] (Galetto, ….) allow to get the probability $\overline{W_i}(t|r)$ that the system remains in the state i for the period r---t and the probability $R_i(t|r)$ [reliability relative to state i] that the system does not be in the state g at time t (given that it entered in i at time instant r). $R_0(t|0)$ is then the probability that the system, in the interval 0---t, does not reach the state g, i.e. it experienced less than g failures: G(t)<g. We have then the ***fundamental system of Integral Theory of Estimates*** [valid for any distribution of time to failure of tested units, i.e. for any "kernel"]

$$R_i(t|r) = \overline{W_i}(t|r) + \int_r^t b_{i,i+1}(s|r) R_{i+1}(t|s)ds \quad ,i=0, \dots g-1 \quad e \quad b_{g-1,g}(s|r) = 0$$

For g=n we get the probability of n failures 1- $R_0(t|0)$ and the Total Time on Test.
If the items on test have constant failure rate λ, then $b_{i,i+1}(s|r) = n\lambda \exp[-n\lambda(s-r)]$, when failed items are replaced or repaired, while $b_{i,i+1}(s|r) = (n-i)\lambda \exp[-(n-i)\lambda(s-r)]$, when failed items are *not* replaced or repaired.
After the test one has the data. Let's suppose n=7 and the time to failure (in the sample) are 60, 105, 180, 300, 400, 605, 890. One can estimate $F_U(t_i)$ and $F_T(t_i)$, and plot the 7 points $[F_U(t_i),F_T(t_i)]$, obtaining the "empirical" curve.
Now Statistics Theory enters the stage. When the reliability of the items is exponential (constant failure rate), the TTT-transform $F_U(t)$ versus $F_T(t)$ is the diagonal of the unit square (the bisector of the coordinate axes). Plotting the "empirical" curve. $[F_U(t_i),F_T(t_i)]$ one finds a line "near" the bisector (β=1), and concludes that a constant failure rate is adequate. When the reliability of the items is IFR, the TTT-transform $F_U(t)$ versus $F_T(t)$ is a convex curve above the diagonal of the unit square. Figure 7 provides some curves depending on the "shape parameter β".
To practitioners this can be fantastic. They collect data, elaborate them and then they compare the "empirical" curve with the "Theoretical Curve" given in figure 7; then they "*know*" the failure distribution and take decisions. Perhaps the situation is more complex ….

- And … what you do if you do not have the figure 7? Are you able to generate it?
- Now let's suppose that we, as managers, decide to save time for decision and we replace the items failed and we continue the test. Can we use the same figure 7?
- Now let's suppose that we, as managers, decide to save time for decision and we repair the items failed and we continue the test. Can we use the same figure 7?
- Now let's suppose that we, as managers, decide to save time for decision and we test more items (e.g. 28) and we stop the test at the 7^{th} failure. Can we use the same figure 7?
- Now let's suppose that we, as managers, decide to save time for decision and we test more items (e.g. 50) and we stop the test at the time instant t=200. Can we use the same figure 7?

IF one is a *sensible Manager* he will answer: "I do not know. I have to study a lot; I have also to be careful if I go to some consultant". IF one is a NOT*sensible Manager* he will answer: "Yes, absolutely".
Let's see now how a problem is dealt in the paper "Total time on test plotting for failure data analyses"; in Section 5 "SYSTEM FAILURE DATA" we read [verbatim] "*It is also possible to use the TTT-plotting technique for analysing failure data from a repairable system. In this case* $TTT(T_i)$ *shall be defined as the time generated by the system until the* i^{th} *failure. If n-1 failures have been obtained until time T*, the time during which the system was observed, then we substitute T* to* T_n *and perform the plotting as before. Also the interpretation of the plot remains unchanged. The TTT-transform has, however, no counterpart. The statistical tests described in Section 4 are still applicable.*" [end of Section]. In Section 4 "STATISTICAL TESTS" we read [verbatim] "*Based on the ideas behind the TTT-plotting some statistical test may be obtained. These tests also provides us with some insight in the stochastic properties of the TTT-plot. …….* "
Now let's use Logic, as we said before. IF *The TTT-transform* does not exist how can one consider "*The statistical tests described in Section 4 are still applicable.*"? They are "*Based on the ideas behind the TTT-plotting …*" which "*has, however, no counterpart.*" !!!! From the TTT-plot one can only have some hints of the non-applicability of "constant failure rate"!!! Nothing more! Moreover, IF one does not know TTT-transform for repairable systems, he should say "I do not know how to find the TTT-transform" and not "*The TTT-transform has, however, no counterpart.*"

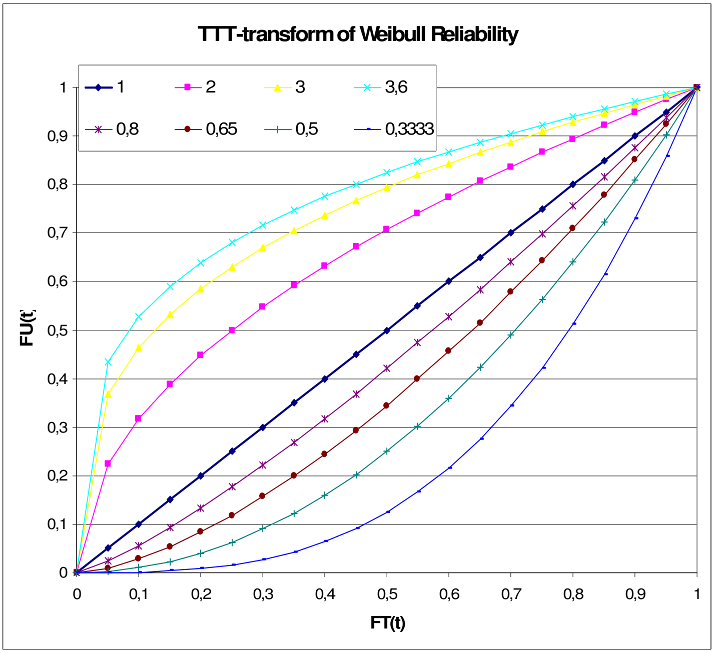


Fig. 7. Weibull TTT-transform [with "shape parameter β"]

As a matter of fact, in 1977, at the *Reliability & Maintainability Symposium*, Philadelphia, F. Galetto provided the Reliability Integral Theory that solves the problem, with his paper "SARA (System Availability and Reliability Analysis)". The theory did exist, not the single formulae: any scholar could have found them. The same theory Reliability Integral Theory, is applicable to maintenance problems, as those presented in "Some graphical methods for maintenance planning"; we will deal with this point in a successive paragraph related to preventive maintenance.

2. Logistics and inventory

Inventories are stockpiles of raw material, supplies, components, work in progress and finished goods that appear at numerous points throughout a firm's production and logistic channel. Having these inventories on hand cost at least 20% of their value per year, therefore, carefully managing inventory levels makes good economic sense, because in recent years the holding of inventories has been roundly criticised as unnecessary end wasteful. Actually good management of inventories improve customer service and reduce costs. Inventory plays a key role in the logistical behaviour of all manufacturing systems. The classical inventory results are central to more modern techniques of manufacturing management, such as material requirement planning (MRP), just-in-time (JIT) and time based competition (TBC).

1st step: the case of "constant (fixed)" demand Let's consider the oldest, and simplest, model – the Economic Order Quantity – in order to work our way to the more sophisticated ReOrder Level (ROL) model. One of the earliest applications of mathematics to factory management was the work of F. W. Harris (1913) on the problem of setting manufacturing lot sizes. He made the following assumptions about the manufacturing system: 1) production is instantaneous, 2) delivery is immediate, 3) a production run incurs a fixed setup cost, 4) there is no interaction between different products, 5) demand is deterministic, 6) demand is constant over time.

Let's consider the problem of establishing the order quantity Q [lot size] for an inventory system, dealt in **"Logistics courses"** and related books. In this field the assumptions are very similar: a single item is subject to "constant (fixed)" demand "λ" [demand rate, in units per year], there is a fixed cost A [ordering cost, in euro] of placing an order and a carrying charge "h" [holding cost, in euro per unit per unit time allotted (often year) to each item in inventory]. If no stockouts are permitted and lead time is zero (i.e. orders arrive immediately) there is a quantity Q (named EOQ: Economic Order Quantity), given by the famous Wilson lot-size formula $Q = \sqrt{2A\lambda / h}$ that minimise the "total cost per year". The inventory can be depicted as a system that starts with Q units (the level, I, of the inventory): we are certain that λt units are sold (delivered) in any interval of duration t; when the level inventory is zero, I=0, Q products are ordered and arrive immediately... and the system starts again from scratch.

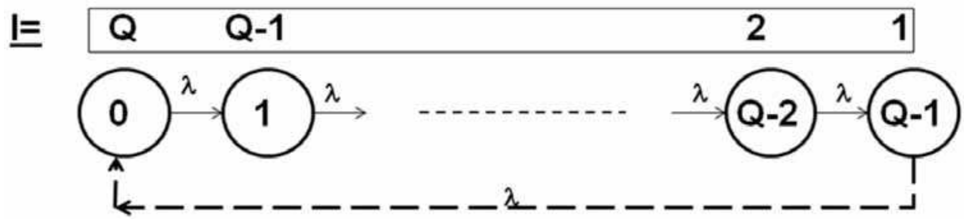


Fig. 8. System inventory states, with fixed and constant demand; state i means i products dispatched

The function depicting the curve of the inventory level I(t) is a saw-tooth line, with constant distance between peaks.

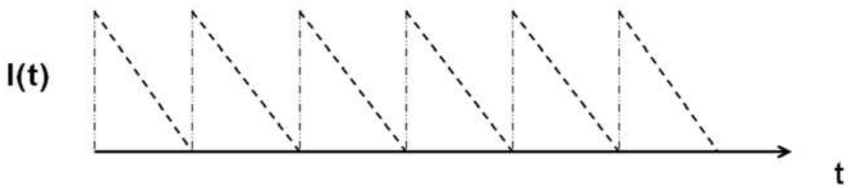


Fig. 9. Level of inventory versus time t

The production cost does not influence the solution and therefore in not considered in the "total cost per year" Y(Q)= hQ/2+Aλ/Q. Taking the derivative of Y(Q), and using elementary concepts of calculus, one gets easily the Wilson formula $Q = \sqrt{2A\lambda / h}$. In this particular case, I repeat, in this particular case, the number of lots ordered per year is N=λ/Q and the optimal time between orders is T=Q/λ, i.e. T=1/N.

Let's now see what happened in a MASTER (after 5 years of Engineering courses) on Maintenance and Reliability, in the lessons for RCM [Reliability Centred Maintenance]:

Wilson formula $Q = \sqrt{2A\lambda / h}$, which holds only in the hypotheses we said just before, was provided to student for buying the spare parts, which obviously depend on the number of failures, which obviously depend on the unreliability, which obviously depend on the time failure, which obviously is a **random variable**!!! ***A serious teacher should have proved that the formula holds true, before teaching it to students !!!!***

2nd step: the case of random demand with "constant" demand rate and steady state of the stochastic process We are going now to consider the demand as a random variable, so introducing the need of the use of probability theory. If we maintain all the previous hypotheses, but the number 5 and 6: 1) production is instantaneous, 2) delivery is immediate, 3) a production run incurs a fixed setup cost, 4) there is no interaction between different products, 5) *demand is random*, 6) *demand rate is constant over time*. We can depict the system as before [and in fig. 10]

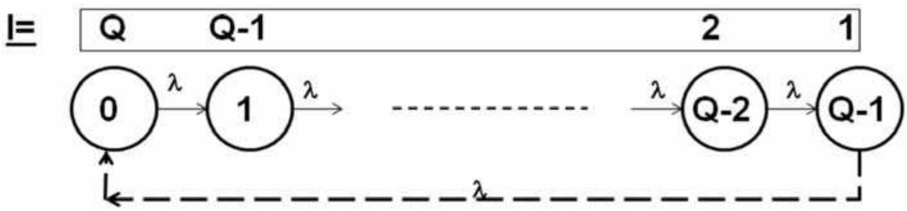


Fig. 10. System inventory states, with random demand and constant demand rate; state i means i products dispatched

where now the "time to sell a new unit (time between demands)" is a random variable exponentially distributed.

The function depicting the curve of the inventory level I(t) is a saw-tooth line, with variable [randomly] time distance between peaks.

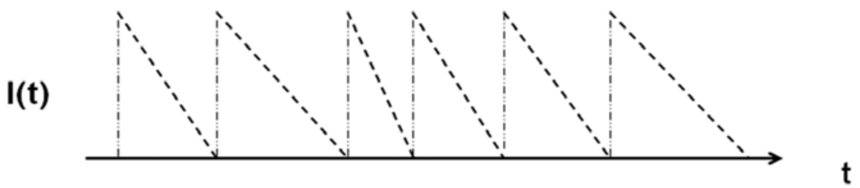


Fig. 11. Level of inventory versus time t

Therefore the probabilistic structure of the inventory system is a Markov process, periodic with period Q. The mean time (holding time) in any state is m=1/λ, the steady-state transition probability from one state i, to the next state i-1 is constant $\varphi_i = \varphi_{i-1} = 1/Q$ [use Markov chains theory]. The "reward structure" is such that the order cost A is associated with the transition from state Q-1 to 0, while the holding cost, per unit time, for state i is $y_i = (Q-i)*h$, i=2 to Q, and $y_1 = h+\lambda A$; the average cost per unit time, g (cost rate), for operating the system in the steady state is $g = [\lambda A + hQ(Q+1)/2]/Q$

The value Q that optimise the cost rate, in the steady state of the stochastic process, i.e. when the time is tending to infinity, is found as the solution of the previous equation. If Q is large, we can ignore the discrete nature of Q [Q is an integral number], assuming it can be considered as a continuous variable: so we can differentiate and set the derivative equal to zero; the solution is (the famous Wilson lot-size formula) $Q = \sqrt{2A\lambda / h}$. If Q is small, we cannot ignore the discrete nature of Q [Q is an integral number], and the solution has to be find numerically.

<u>3rd : the case of random demand with "variable" demand rate and steady state of the stochastic process</u> We are going to consider again the demand as a random variable, (need probability theory), maintaining all the previous hypotheses [as in the 2nd case], but the number 6, : 1) production is instantaneous, 2) delivery is immediate, 3) a production run incurs a fixed setup cost, 4) there is no interaction between different products, 5) *<u>demand is random</u>*, 6) *<u>demand rate is **NOT** constant over time, but it varies with time, identically after any transition from a state to the following one</u>*.

We can depict, again, the system as before [and in fig. 12]

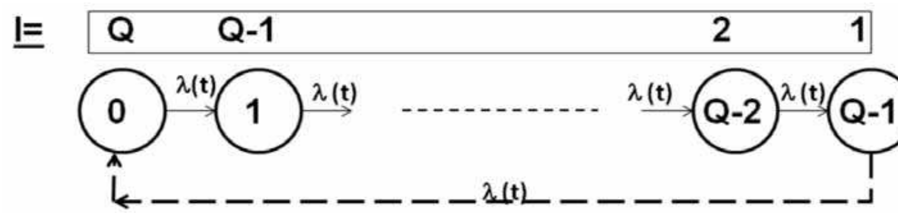


Fig. 12. System inventory states, with random demand and variable demand rate; state i means i products dispatched

where now the "time to sell a new unit (time between demands)" is a random variable "identically" [but not exponentially] distributed; let indicate the probability density of the time between transitions as f(t) [related to the "rate" λ(t), with cumulative distribution F(t)]; its mean is m.

The mean number of state transitions in the interval 0-------t, M(t) is the solution of the integral equation

$$M(t) = F(t) + \int_0^t f(r) M(t-r) dr \tag{1}$$

The related intensity of state transitions, at time t, is m(t)=dM(t)/dt, the solution of the integral equation

$$m(t) = f(t) + \int_0^t f(r) m(t-r) dr \tag{2}$$

In the process steady state we have M(t)≅t/m and m(t))≅1/m, for $t \to \infty$. The function depicting the curve of the inventory level I(t) is a saw-tooth line, with variable [randomly] time distance between peaks, too. [fig. 13]

Therefore the probabilistic structure of the inventory system is a semi-Markov process, periodic with period Q. The mean time (holding time) in any state is m [the mean of the distribution] identical for all the states; then the steady-state transition probability from one state i, to the next state i-1 is constant $\varphi_i = \varphi_{i-1} = 1/Q$ [use semi-Markov processes theory]. The "reward structure" is such that the order cost A is associated with the transition from