MEASURING HISTORY: DOES HISTORICAL CAR PERFORMANCE FOLLOW THE TRIZ PERFORMANCE S CURVE?

Chris Dowlen
London South Bank University

ABSTRACT
After an outline of the four curves proposed for measuring historical product behaviour by the TRIZ system and a brief summary of previous work to determine the development of car history, the paper investigates the assessment and measurement of performance throughout the history of the car. This is done by taking a historical investigation of performance criteria such as engine power, maximum speed and acceleration. A factor analysis is also carried out on performance parameters and the first two factors are presented as a two-dimensional performance map that could be used as a design tool. The paper then questions whether this is what is really meant by car performance and discusses the difficulties of measuring this. Car developments in the late 1930s are taken as an example to illustrate some of the nuances that need to be captured. The work has indicated that the TRIZ process is a somewhat simplistic curve that does not take into account the historical data in this case.

Keywords: Car history, TRIZ, performance measurement, product development

1 INTRODUCTION
The paper is investigating whether it is possible to confirm that the TRIZ S-shaped performance curve applies to cars from the end of the 19th century to the current time. It asks exactly what is meant by the term performance, and how it might be measured. It also provides an example of how significant changes affected the direction of car development in the late 1930s.

2 TRIZ HISTORICAL S-CURVES
TRIZ is intended to be a method of developing creative processes. However, almost in passing it does succeed in being one of the few techniques that is prepared to measure historical developments using numerical information.

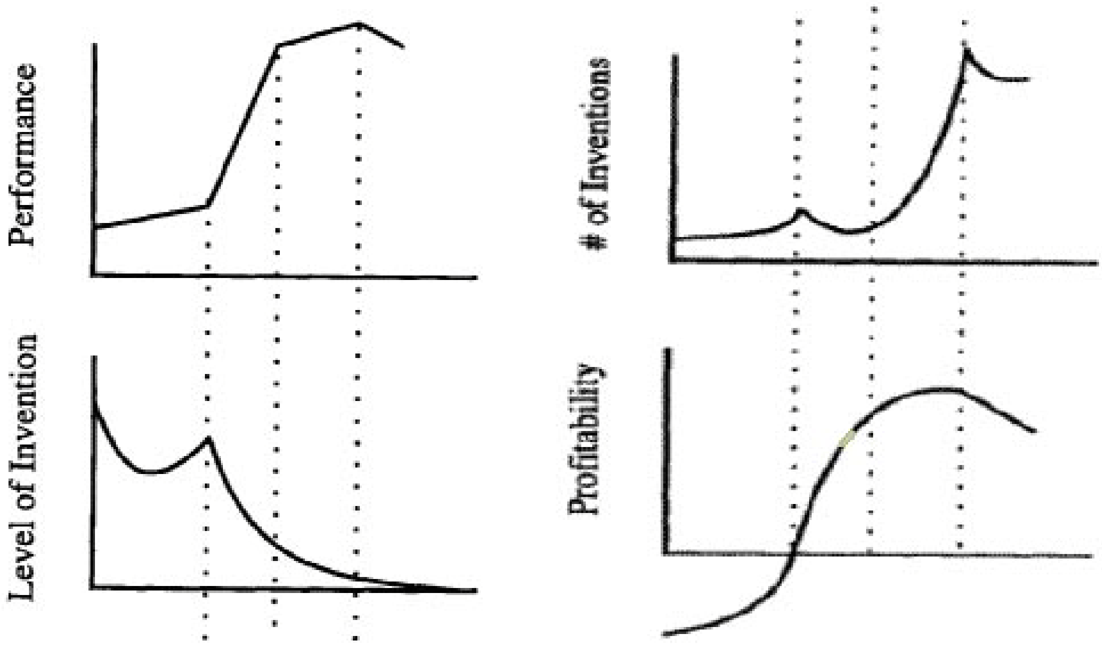

Figure 1: Altshuller's 'Lifelines' of Technological Systems [1]

Altshuller, in his general introductory book on TRIZ [2] simply describes periods in a system's life as:

1. selection of parts for the system
2. improvement of parts
3. dynamization[1] of the system
4. self-development of the system

General TRIZ texts introduce a more structured form of measurement, using four curves that measure aspects of system development: performance, level of inventiveness number of inventions and profitability. These curves are copied in Figure 1 from Darrell Mann [1], who took them from Michael Slocum [3] – who states that they come from Altshuller [4]. The one for performance is described as being an S-shaped curve.

Mann and Slocum develop curves appropriate for particular systems and use these to assist the process of system development. Slocum, in particular, shows how an analysis of system performance over time indicated that the system was due for significant novel developments.

When Altshuller introduced his four time periods, he used a description of aircraft development as an illustration. This suggests that the curves should be applicable to both products and systems.

3 CAR HISTORY MEASUREMENT

Cars have been around since the late 19th century. There is a considerable body of knowledge about their development and history, but little of this is couched in numerical terms. It was envisaged that product, and hence car, developments, followed principles of paradigmatic development, with designers producing state of the art products and changes implemented as a series of steps or paradigm shifts, in a similar way to those in scientific developments suggested by Kuhn [5]. These were proposed in a paper presented to ICED in 1999 [6]. At this point the suggestion was speculative.

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[1] Altshuller used US spelling for this

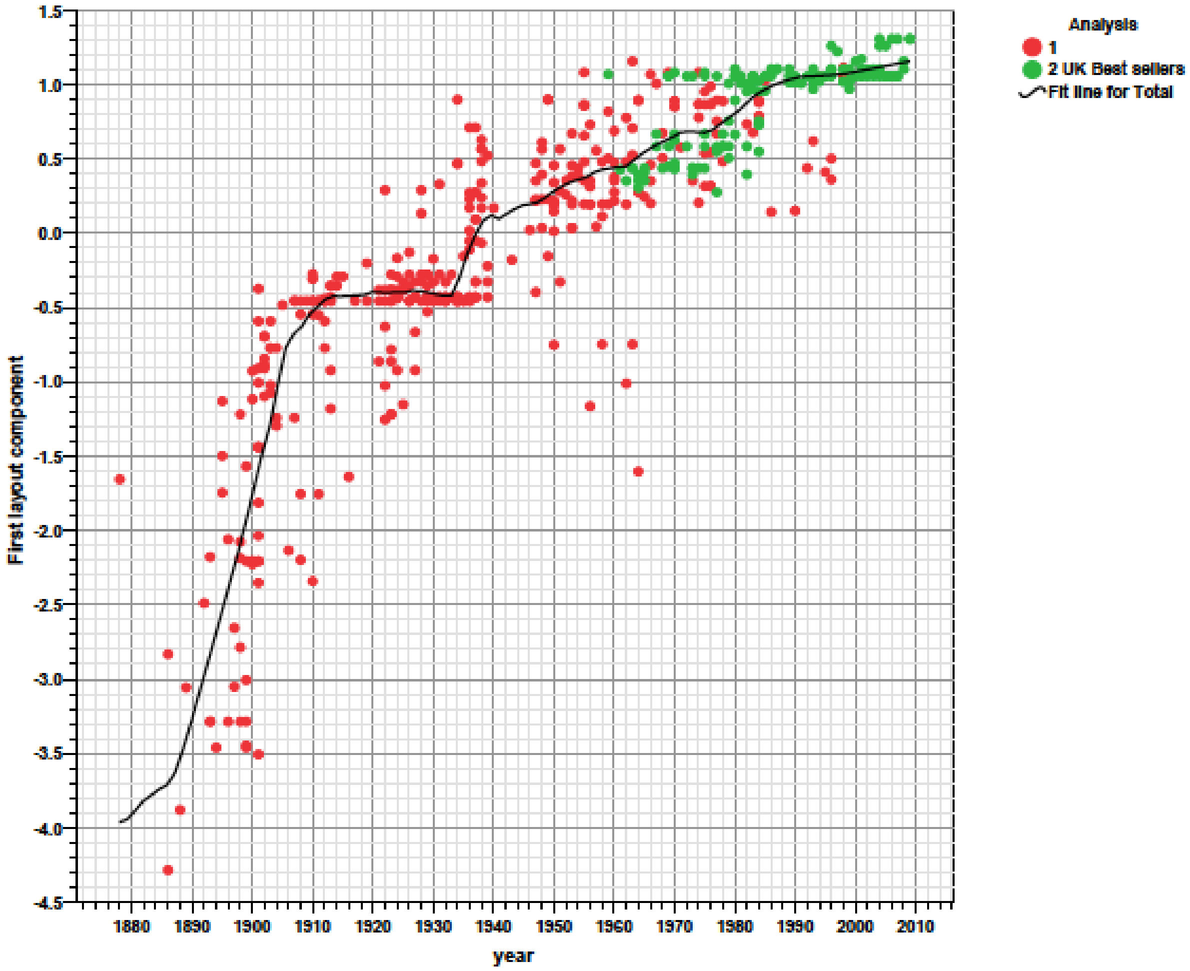

Figure 2: Car layout: the first principal component plotted against year

Analyses have been carried out since, investigating layout and form development using categorical principal component analysis [7]. The process results in a series of components (similar to factors obtained from a factor analysis) that simplify the arrays of parameters using correlations. The first component is the one that explains the greatest variance, and therefore it is the most useful single-figure output from the process. Separate analyses were carried out for layout and form. These analyses demonstrated that for layout design, such steps take place, whereas for form design developments correlate but the changes are not so step-like in character.

These analyses used a database of cars dating from 1878 to 1999 developed on a pragmatic basis with no attempt to provide a representative sample. The database was then developed to include more representative cars in the shape of best selling models. Although cars are clearly a global product, the initial model list of best-sellers was the UK one, available from the UK Society of Motor Manufacturers and Traders annual year book [8]: although this has been published annually since 1928, 1965 is the earliest year that distinct sales figures are available for specific models.

Figure 2 gives an example of a graph that has been created from this process. This is of the first component of the layout analysis: the stepped nature of developments can be seen in the horizontal lines of points on the graph. It should be noted that the rise in this component over time is probably because later layout categories tend to be allotted higher numbers than earlier ones and hence they will tend to produce a rise in the first component.

These curves do not claim to measure the same things that the TRIZ curves measure, although this curve has S-shaped similarities to the TRIZ performance one and it clearly describes development of the product. In order to investigate the TRIZ curves it is essential to determine curves that are attempting to measure the same things as the TRIZ ones.

4 ALTSHULLER'S FOUR PERIODS APPLIED TO CAR HISTORY

If one were simply trying to describe Altshuller's four periods of car history by inspection of the typical car from a particular date, we might end up with sets of dates that are as follows:

4.1 Selection of parts for the system

The general system parts such as engine, transmission, wheels and their arrangement seems to have been largely carried out by the end of 1904. Some people, such as Burgess-Wise [9] suggest that this date marks a significant adoption of a definitive layout, whilst others, such as Olley [10], suggest that the adoption is more gradual. Cars from this period demonstrate significant variations. Figure 3 shows some examples.

Figure 3: 1888 Benz, 1901 de Dion Bouton, 1903 Mercedes, 1903 Cadillac

These cars show significant variation: three wheels, coffee grinder steering, rear drivers, chain drive and rear and mid-engines. All of these happen to have petrol engines, but this was not always the case.

4.2 Improvement of parts

Figure 4: 1905 Renault, 1918 Bedford Buick, 1933 Austin Seven

This probably means that the selection, numbers and major arrangements are generally decided upon. In car history terms, it would probably relate to the period from 1905 to about 1930, which in the UK is a combination of the Edwardian and Vintage periods. Cars have a reasonably similar appearance and layout. This is a tight layout, and the majority of layout parameters remain reasonably fixed for the whole of the period. Figure 4 shows some examples.

4.3 Dynamization of the system

With this period Altshuller suggests that the parts begin to lose their own image. In car history this would equate to some degree to stages such as integration of parts under a streamlined whole, car forms where one is not quite sure where the component parts are located, and so on. It probably relates to a rather lengthy period from the mid-1930s when the process of streamlining and integration of things like headlamps started, to the late 1950s or so, although it is extremely difficult to locate the end of this from Altshuller's descriptions. Figure 5 gives some examples that might relate to this integrative historical period.

Figure 5: 1935 Renault Nervastella, 1947 De Soto, 1960 Porsche 356

4.4 Self-development of the system

Altshuller is not able to find an example of this from the aircraft industry for his illustration. He is talking about products that are able to reconfigure themselves as necessary. He suggests that this has yet to be revealed when describing aircraft. This may also be the case for cars. In any case, it seems difficult to imagine how cars might be configured into this arrangement, particularly if humans are still intending to drive them and if there is still this seeming love affair for the car. If it seems to be fanciful for aircraft, it may also be so for cars, even though the car can be thought of as a reasonably mature product.

It would seem that there is some difficulty in attaching Altshuller's basic descriptions of periods to car history and significantly more difficulty in producing some meaningful metric that would capture the difference between the four periods.

5 MEASUREMENT OF CAR PERFORMANCE

The first issue for measurement is that of being able to create a meaningful point that represents the car at a particular date. It is clear that it should be a measure of central tendency of some sort, but which one? And how should it be determined? It is quite clear that the argument that any example of a car provides some data is a valid argument, but this only holds if sufficient car examples are in the database to enable some confidence to be attached to such a central tendency measurement. If a point estimate such as a measure of central tendency it is usually possible to calculate an interval estimate of some sort that will provide a set of positions for confidence. This is generally reasonable where there is clearly a single paradigm in operation for car design, but when there is a change taking place the distribution of data can start to assume a bimodal distribution, broadening out the confidence position for the central tendency measurement at this point. This can be seen between 1960 and 1970 in Figure 2. Attempting to short-cut the problems with an unrepresentative car data collection can to some extent be overcome by seeking to measure cars that are perceived as being more representative of the overall position, such as those obtained form the sales figures. There is also the question of whether the sample selected should be of each car or of each different model of car. Should it be weighted to allow for the sales of each model, or not? The sales data do not differentiate between different examples of models, but simply measures overall sales: no measure is taken of whether these represent hatchbacks, saloons, estate cars, high performance models or whatever. A range of these has been used. In some cases, two completely different models are included in the one figure, making differentiation impossible. Such data are acting in a similar way to simply providing suitable examples.

5.1 Measuring Performance – the traditional way

The next difficulty is to determine exactly what is meant by the term 'performance'. Describing a car as being a high performance model means that it goes faster – in that it has greater power, higher top speed and accelerates faster. Taking this somewhat simplistic view of car performance nevertheless results in obtaining some useful data. Figure 6 shows data for car engine power, maximum speed and acceleration for different dates. In this figure engine power is in red, maximum speed in green and acceleration in blue. The power figure has been relatively easy to obtain from the earliest cars onwards, so is available for a significant number of the examples in the database.

What is seen is that power rises generally, but with a significant dip taking place for ten years or so from the Second World War onwards. It may be related to such non-motoring events as the period of austerity and rationing in the UK after the war, and the Suez Crisis of the late 1950s, both of which might have made more economical motoring more popular for a period. Maximum speed data is also available for a lot of cars and is reasonably consistent in its measurement.

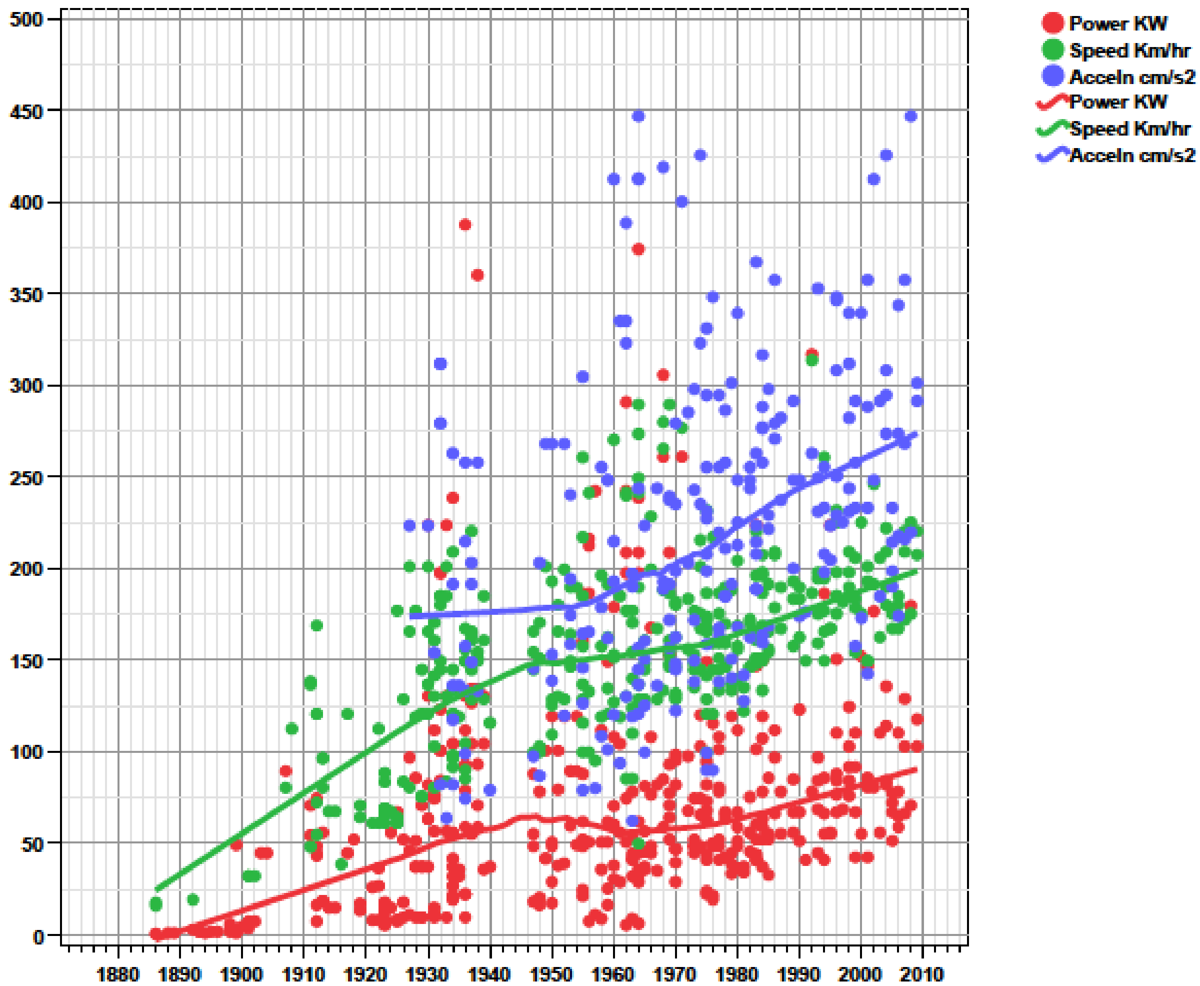

Figure 6: Measurements of car performance at different dates

A similar lack of levelling off is also seen in the quest for more speed – although from the Second World War years there is a slight flattening, suggesting that designers were starting to become interested in efficiency – the achievement of higher speed with less power.

Acceleration includes a certain amount of compromise. This data only goes back to 1930 or so: it could not be found for cars before this date. The available figure is a time for acceleration from zero to 50mph (80.45 kph), 60mph (96.45kph) or 100kph. A comparative figure for these three categories is needed. The average acceleration figure for the maximum acceleration run has been used for this, although it will not be the same for 0-50mph as 0-60mph figure, making for a compromise. The figure has been multiplied by 100 to enable it to fit with the scale of the graph.

None of these power graphs shows an S-shaped curve – there is little evidence for a flattening out of the curves as time progresses, even though the car might be reasonably perceived to be a mature product.

5.2 Measuring car efficiency

It might be a more useful suggestion to investigate some measure that has to do with increasing efficiency, suggesting that this might, in fact, be a suitable measure of performance in a slightly different manner. This could, for instance, be of engine performance, in which case a figure such as power for a given engine volume could be useful: or alternatively, power to weight ratio could be used as this relates closely to acceleration efficiency. However, it would seem that a measure such as speed divided by engine power might be most appropriate. Figure 7 gives a graph of a series of suitable measures: it should be noted that the points and curve for speed for given power has been factored by ten so it scales similarly to the other curves and can be seen on the same diagram.

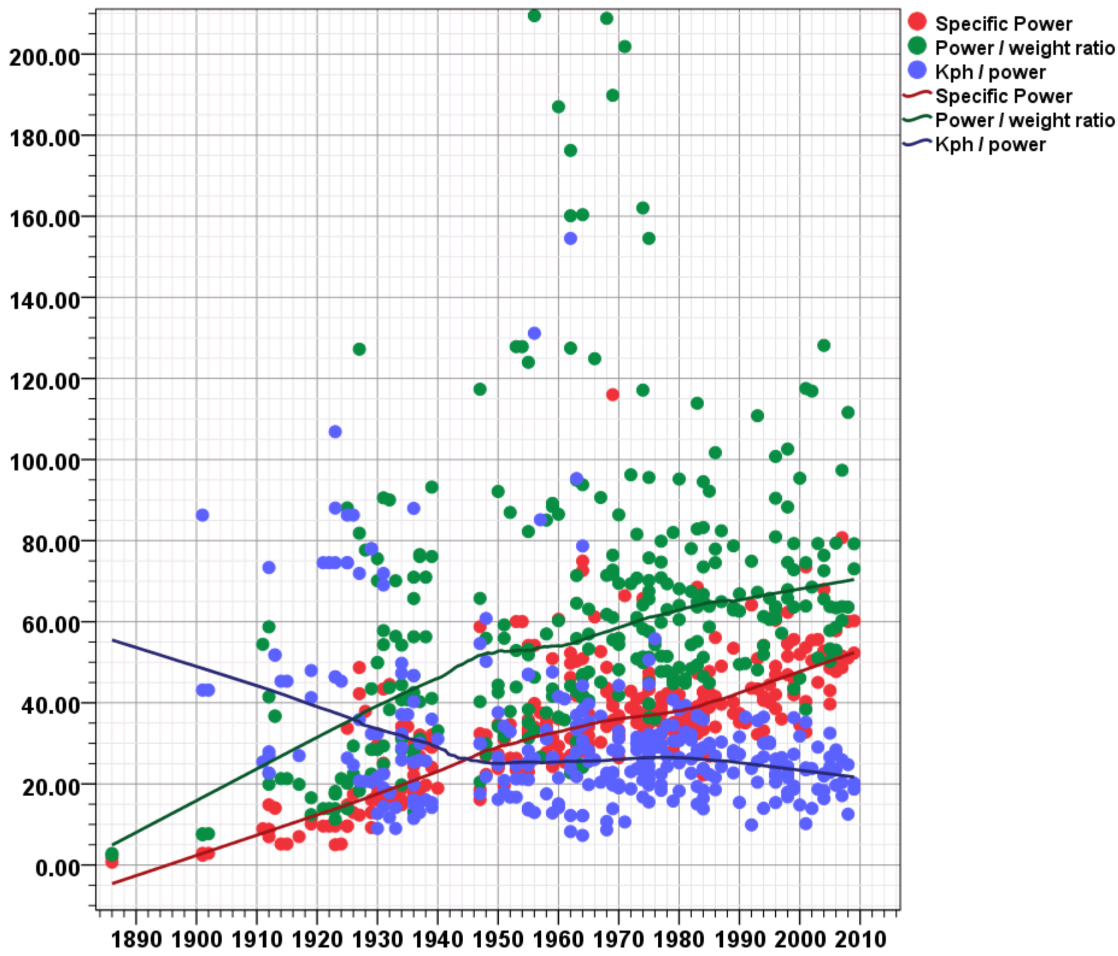

Figure 7: Possible efficiency measures for cars

This gives some interesting results, in that whilst specific power and power to weight ratios have increased significantly, the speed to power ratio has decreased, which simply seems to be a factor of the physics concerned in that the air resistance part of the power requirement increases as the cube of the speed. The specific power curve indicates a significant and continuing rise that shows no sign of lessening. Although there seems to be a gentle decrease in slope of the power / weight ratio curve, this seems so gentle that it hardly represents an example of an S-shaped curve. There are interesting inflections in both the specific power curve and the Kph / power curve at around 1980, suggesting that perhaps something occurred at this point. The suggestion is that car weights started to increase because of the start of customer awareness of safety, and that there was a noticeable drive towards efficiencies both in engine design and aerodynamics in the wake of the global fuel crisis of the mid-1970s.

5.3 Using a multi-parameter approach

An approach similar to that taken with analysis of layout and form could be taken with various variables that might have some impact on car performance. These are engine capacity, power, torque, frontal area, weight, maximum speed and acceleration. The process used was a factor analysis [11].
Figure 8 shows the results for the first two factors.
These factors show slightly different time behaviour. Factor 1 rises through the whole time period, with an increase in slope noticeable from the mid 1970s onwards. The second Factor increases to the mid 1930s, and then decreases for a period, to rise again from the mid 1970s onwards. It is clear that something takes place during the mid 1970s that affected car performance, which may have been the first fuel crisis. A particular difficulty is noted (and with all factor-type analyses) in that it is difficult to describe exactly what each of the factor represents: this is only possible by a process of examination.

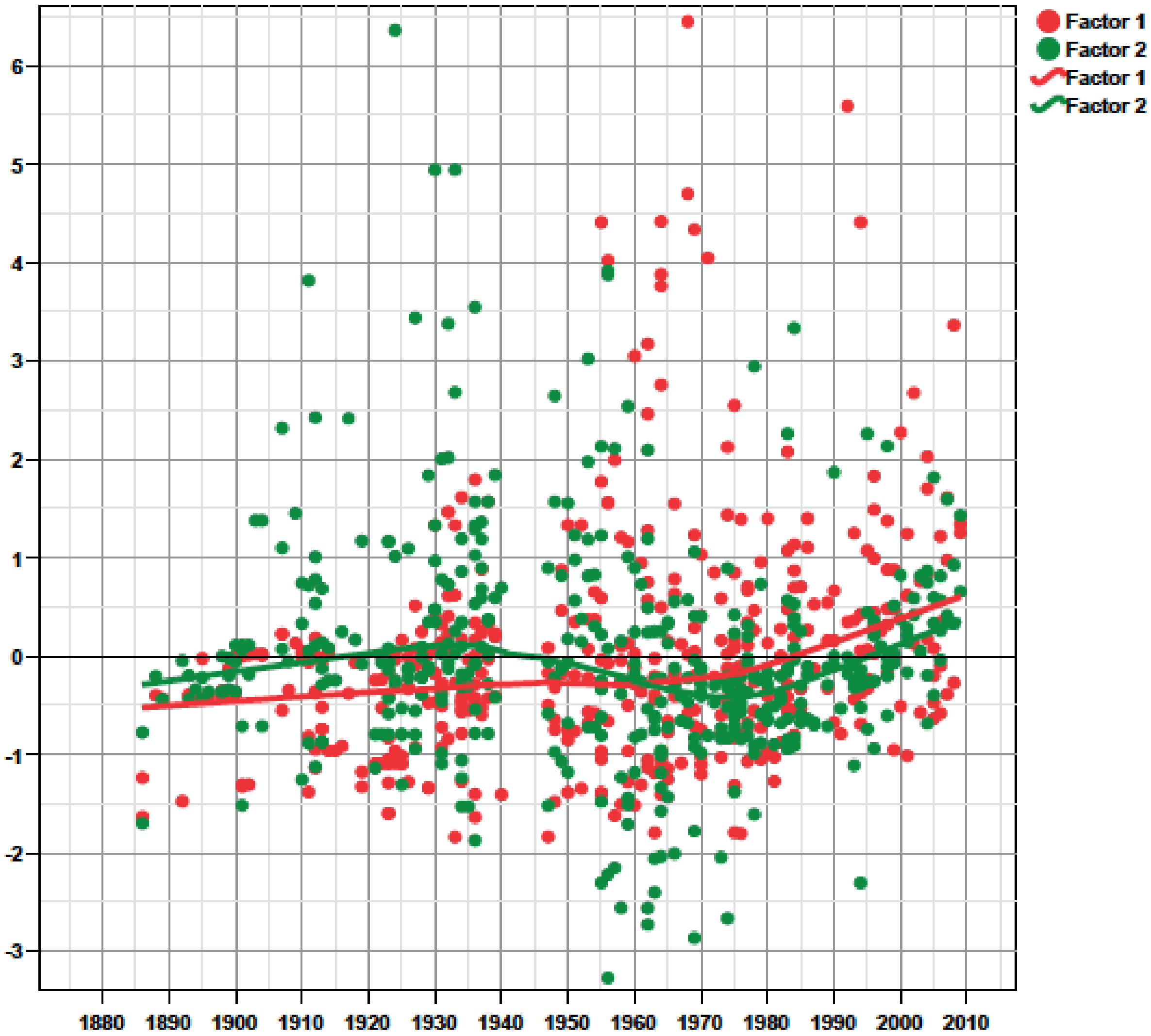

Figure 8: Factor analysis scores plotted against car date

If the factors are plotted out against each other, a two-dimensional map of car performance is created. This is shown in Figure 9. The picture is not enhanced by the addition of colours or other markers to indicate car dates – this only serves to confuse, but some pictures have been superimposed to help to see what is happening..

On examining the individual points on the diagram, the higher powered cars are to the right and the lower powered ones to the left. Lighter cars find their way to the bottom, and heavier ones are towards the top. So the lower right quadrant contains stripped down sports cars and racing cars: the upper right one the high-powered but heavy limousines: the upper left one the low powered heavy cars and the right lower one the economy models: low-powered, light cars. There is a tendency for the earlier cars to be on the left of the diagram with later ones to the right. If going for efficiency and performance, then the lower right is the place to be: if the compromise means that a lot has to be carried, then the upper part of the diagram is where there is a tendency to be. The further towards the lower right, the higher the performance. So this creates a design tool for performance. Factor 1 may be described as an out-and out performance factor, and factor 2 describing some measure of efficiency.

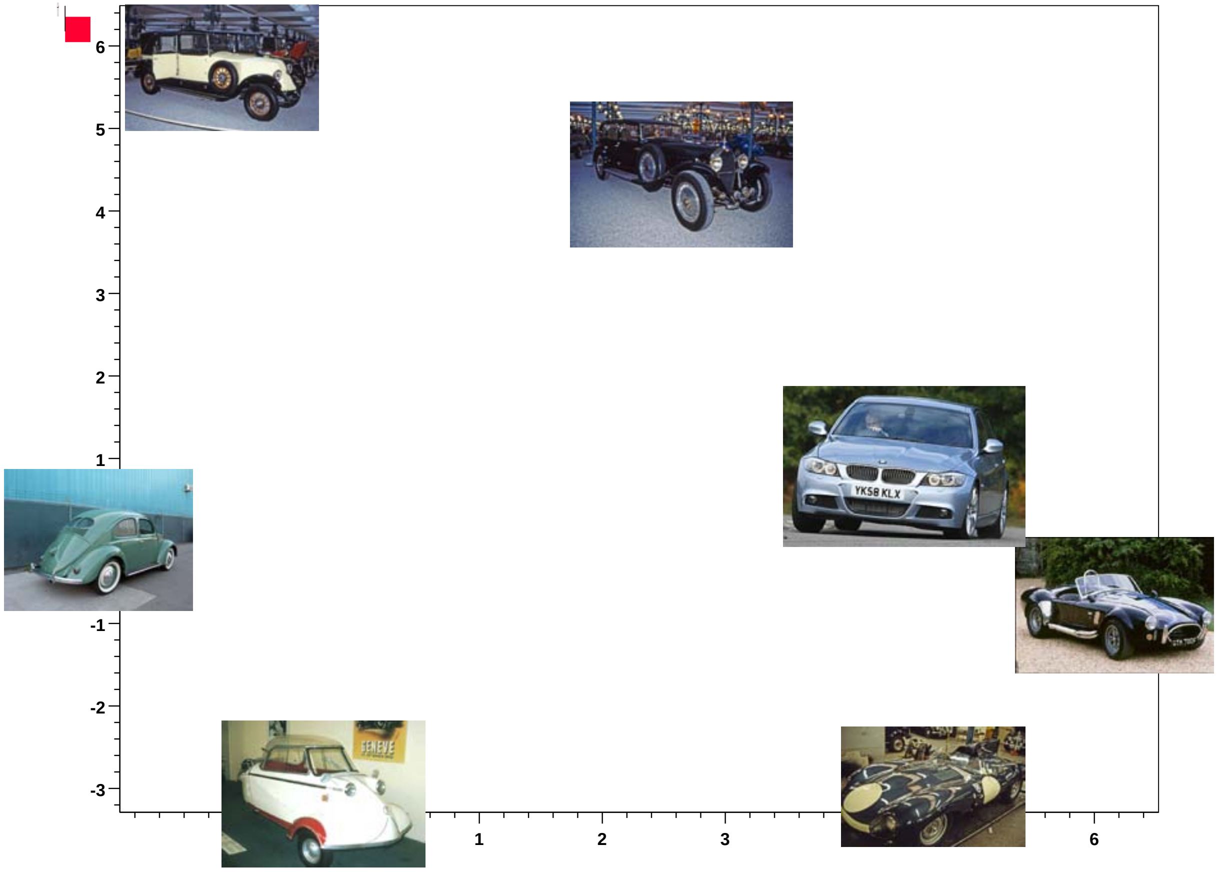

Figure [illegible] Factors plotted against each other to give a two-dimensional car performance map with car pictures superimposed

5.4 Measuring performance – what might actually be meant in TRIZ

All these approaches might perhaps be called traditional meanings of performance measurement. But it may not be quite what is meant by the term performance as interpreted by TRIZ. Mann [1] talks about the selection of suitable performance measures and gives an example where a specific criterion has been achieved at some point in time and therefore after that point it becomes a given and hence not a suitable criterion to use as a performance measure.

When cars are tested by magazines there are typically a series of scores for different aspects of the car.

A small selection of magazines carrying out road tests on cars produces the mixture of assessment processes and criteria are shown in Table 1. Note that *Which?* (the UK consumer magazine) [14] gives a road test that is assessed by using stars and an overall rating that is assessed using a score, which involves various other non-road test pieces of information such reliability, economy and owner satisfaction.

It is clear that standards differ for different magazines, which perhaps shows their market interest and readership. They also differ for different dates. And it is also clear that what car customers want is different at different times: the goalposts move around and a car with an *Autocar* overall rating in 1975 of 3.61 (out of 6), which translates to 60 out of 100, or 3 stars out of 5, would be unlikely to produce the same rating in 2010.

So it is difficult to measure performance consistently over time, even with a consistent magazine as a source of data, such as *Autocar*.

Table 1: Assessment processes for car tests

Magazine	Autocar[12]	Autocar[12]	Classic and Sports Car [13], comparative test	Which? [14]
date	2010	1975	2010	2010
Marking system	Stars	Numerical	Stars	Numerical or stars
Maximum	5 stars	6	5 stars	100 Whole stars
Step size	½ star	0.01	½ star	1
Overall rating	Yes	Yes	No	Yes
Criteria	Design and engineering Interior Performance Ride and handling Buying and owning	Performance Steering and handling Brakes Comfort in front Comfort in back Drivers aids Controls Noise Stowage Routine service Ease of driving	Interior Styling Engine Drivetrain Performance Handling	Drive performance Handling Ride comfort Brakes Noise and refinement Behind the wheel Visibility & parking Getting in & out Seat space & comfort Boot & storage Heating & ventilation

5 AN ILLUSTRATION OF IMPROVEMENT

An illustration of how car design metrics can be used as a pointer to indicate beneficial changes can be seen from Figure 2. It is clear that was a measure of consistency in car layout from about 1905 and this resulted in design stagnation until the mid 1930s. Then there was a significant shift. Investigation suggests this shift is due to two issues. One was the adoption of independent suspensions, particularly at the front of the car, and the second was the introduction of pressed steel bodies. This first was driven by development in the understanding of vehicle dynamics, particularly within General Motors [10]. This developed understanding of the interaction between car handling and ride, and how roll stiffness increased by a step change with the change to independent suspension, as the moment arm for roll resistance changes from the width of the spring base for non-independent suspension to the track (distance between the wheels) for independent suspension. This enabled softer suspensions to be fitted with the same or reduced roll, resulting in improved ride characteristics. It meant cars became more stable, as this tended to promote stable understeer rather than unstable oversteer. The first effect of this was to move engines forward, as there was no axle crossing the width of the car.

Figure 10: 1933 Ford Model Y and 1936 Fiat 500

This gave more cabin space for people. The clear change that provided the step change, however, was the ride improvement. This was driven by customer perception. Pressed steel bodies, however, were due to the market need to build more cars and the economies of scale from assembling car body shells more quickly in quantity: it did not necessarily result in immediately perceived improvement of quality from the customer's point of view, but it certainly did from the manufacturer's. Figure 10 shows pictures of cars from each side of this change – but it should be noted that style changes are taking place at the same time but in a less predictable fashion. The Ford on the left has the screen set significantly further back than the Fiat – which has its little engine moved totally forward of the front wheels, in front of the radiator.

6 CONCLUSIONS

Whilst TRIZ suggests that a performance metric might follow an S-shaped curve, it would appear that the reality is significantly more complex – at least for the car. There is considerable difficulty in determining exactly what performance parameters might be construed as suitable for measurement, and even then an investigation suggests that the way that they might be most effectively measured at different points varies with time. A further point is that a current, backward-looking approach might be fine for describing historical developments but it is always tinged with emotive values of cars and the perception of classic, even antique status for some. There is some evidence that development stagnates at particular times and sudden developments occur: curves are also affected by political events – even by tax changes – and more major effects such as wars, Middle Eastern pricing policies, worldwide and local depressions and by many other factors. The S-curve seems to be a simplistic and probably idealistic approach to developmental theory and the real story is significantly more complex. Studying the available metrics and developing others to suggest suitable timelines can start to explain some of the complexities of developments. The current answer to the posed question is inconclusive: further work is needed, particularly to develop the overall merit rating scales from car tests to try to establish overall developments in terms of press opinions, which are intended to mirror customer expectations. Although tests are available back to the 1920s, an overall scoring system seems to have been introduced in the *Autocar* only from mid 1975 onwards, which makes its utility limited in terms of behaviour over time. Before that date it is necessary to scour the narrative for specific value words such as 'excellent' 'good' and so on – bearing in mind that road testers have tended to be complimentary rather than condemnatory in general.

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