Systematic Vehicle Design Innovation

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ABSTRACT

The paper suggests that the increasing similarity of automobile designs is in large part due to the application of essentially the same design tools and methods across the industry. In large part, these design tools are based on strategies of trade-off and optimisation, and are thus fundamentally unable to help derive breakthrough innovation. The paper describes how innovation methods derived from the study of over 2 million patents have been applied to the design of a variety of different automotive systems – from individual components, through major assemblies to total system concept – and examines some of the systematic breakthrough solutions that might be possible.

INTRODUCTION

The automobile industry is relatively mature. The large majority of car and car-component designs seem to be tending towards very similar solutions. The paper suggests that this convergence is in large part due to the application of essentially the same design tools and methods across the industry. All of these design tools are essentially based on strategies of trade-off and optimisation. Unfortunately, systems - including design methods – hit fundamental limits. The problem with 'fundamental' is that it means precisely that. When systems hit limits, the only way to derive additional improvement is to change the system. Innovation research conducted over the past 60 years has demonstrated that there are means of systematically evolving systems to new levels of capability. The paper discusses three such strategies:-

1) evolving design capability by eliminating trade-offs and compromises
2) evolving design capability by recognising that other industries have already solved many of the limitations currently being experienced in the automotive sector, and that those solutions can be translated into automotive-specific terms

3) evolving design capability by taking advantage of the high level of predictability of technology evolution trends.

The paper discusses how these strategies are being used to change the way that many organisations think about the innovation process. Ford, General Motors, and Mitsubishi are already adopting the systematic innovation methods across a wide range of engineering disciplines. Case studies taken from these companies and others currently being worked with car manufacturers in mainland Europe are discussed. They cover a wide spectrum of applications from detailed examination and trade-off eliminating solution of problems at the component level, through to demonstration of the evolution of designs at the major assembly (drive train and cabin architecture) and ultimately total vehicle level. At the total vehicle level, the paper suggests how evolving market and technology evolution trends can be expected to have a further pronounced effect on the future of vehicle design.

The first section of the paper, however, provides a brief introduction to systematic innovation methods and the underlying principles of why and how systems evolve:

SYSTEMATIC INNOVATION

The evolution of systems of all descriptions can be characterised in terms of s-curve profile graphs in which some measure of 'goodness' (value, benefit, cost, etc) is plotted against a time axis. The flattened profile at the top of the s-curve – usually taken to signify a 'mature' system incapable of further improvement – has been shown to be a fundamental phenomenon of evolution. Put simply, systems – including a generic system that might be called 'automobile design' – hit fundamental limits and no amount of optimisation of that system will realise a target level of 'goodness' inconsistent with that limit. Research on the Theory of Inventive Problem Solving, TRIZ (Reference 1) has uncovered several features of system evolution, the principal one of which is that the dynamics governing the shift from one s-curve ('paradigm') is governed by the successive emergence and resolution of contradictions (Figure 1). This feature applies at all levels of a system hierarchy – whether it be the evolution of nuts and bolts to the evolution of the automobile, to the evolution of the super-system surrounding the automobile.

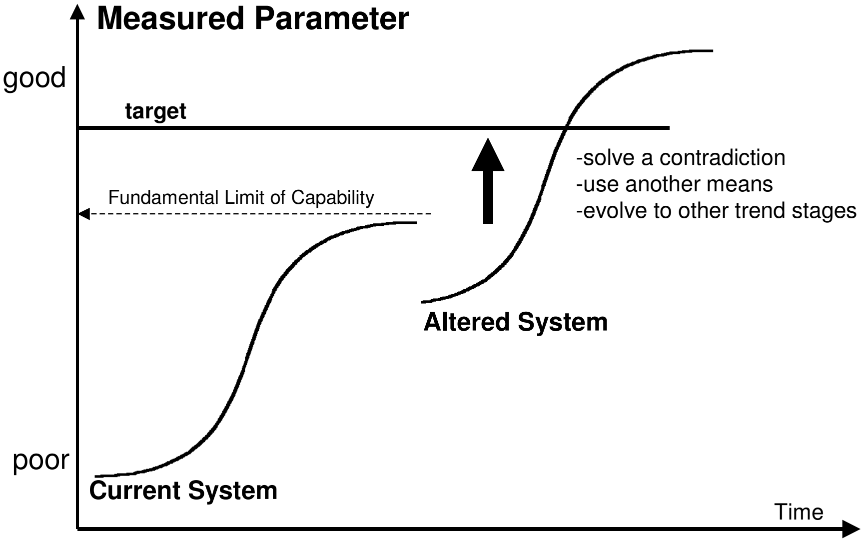

Figure 1: Evolutionary S-Curves and the Mechanics of Evolution

The mechanisms, then, by which systems shift from one s-curve to the next have been codified and formed into problem solving tools building on the successful solutions of others. In terms of these s-curve shifts, TRIZ contains three main tools: The first is a functionally classified knowledge base that makes it possible for users to identify the means by which other industries and problem solvers have solved certain generic problems. Thus, for example, the automotive industry has evolved certain strategies for painting the surfaces of a vehicle. This is a fairly specific problem and thus, there are not many alternatives to those already generated by the industry. If the problem is abstracted, on the other hand, to one of 'moving liquid' or 'attaching a liquid to a solid' or even 'drying a liquid', suddenly, it becomes possible to access a much larger number of alternative solutions – Figure 2 – several of which may offer the automotive industry better ways of delivering the function. This type of failure to look for or connect to solutions from other areas relates also to the phenomenon of 'psychological inertia' (Reference 2). The paint operation is one of the bottlenecks in car manufacture, and one of those s-curve scenarios where the systems in use are very well optimised and it is very difficult to achieve even very small process time improvements. It is of course also a relatively small and specific part of the automotive design and production process. The importance of this kind of cross-disciplinary functional thinking only really becomes apparent when all of the other different functions involved in the automotive industry are considered relative to a global database of other known means of delivering each and every one of those functions.

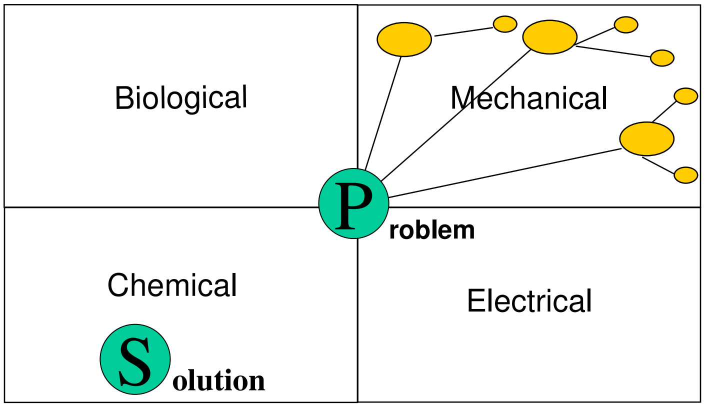

Figure 2: Solution Spaces
(Mechanical engineers look for mechanical solutions to problems)

A second means of identifying the jumps between s-curves is to use the trends of evolution part of TRIZ. This tool has resulted from the uncovering of a number of generic technology shifts as patents have been studies over the course of the last 50 years. Reference 1 describes 35 such trends. Figure 3 illustrates one of them – a trend known as 'object segmentation' – and indicates its likely application to the evolution of bearing systems.

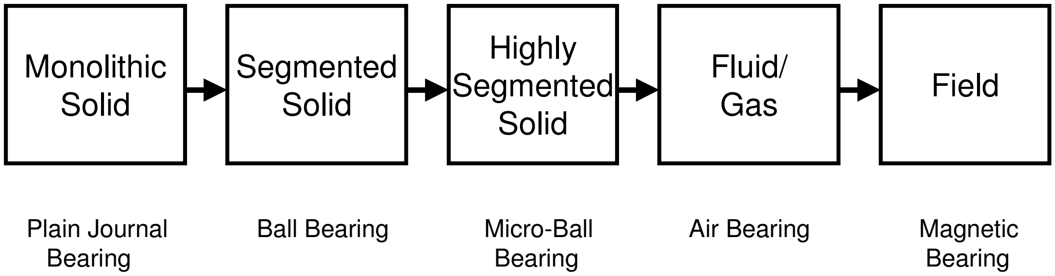

Figure 3: Example Technology Evolution Trend and Application to Bearing system Design

This trend hints at some of the possibilities for predicting the future evolution of the automobile from a bottom-up analysis of the components from which it is constructed. The evolution towards magnetic bearings, for example (an evolutionary direction shown to be beneficial from several perspectives in other industries already) would be highly consistent with the 'more electric' directions emerging elsewhere in automotive systems architectures. The shift towards increased use of 'fields' (electrical, magnetic, etc) is a recurring theme across several of the other TRIZ trends in fact.

The TRIZ trends are increasingly being used as a means of identifying the 'evolutionary potential' of a given component or system (Reference 3). This is a quantifiable evolutionary state resulting from a comparison between the known trends and the current position of a given system along each one.

Taking this concept a stage further, is the concept of 'evolutionary limit'. The so called 'evolutionary limit of a system corresponds to that state where a given component or system has evolved all the way along all of the known trends. This evolutionary limit concept is useful in the strategic sense - for example in the allocation of R&D spend to achieve the greatest benefit per amount of money invested. Introducing another TRIZ pillar, that of 'ideality' and the idea that all systems evolve in the direction of an ideal final result (defined as 'delivery of the function with zero cost or harm', or, more controversially, 'delivery of the function without the need for the system'), however, highlights certain dangers in this evolutionary potential concept. That danger is illustrated in Figure 4, and may be described as follows: A system may evolve to its evolutionary limit and still not have achieved its ideal final result. This leaves open the possibility that it was not the right start point for achieving ideality, and thus that certain start points will lead only to an evolutionary dead-end some way short of the level of ideality that may have resulted from a different start point. This phenomenon serves to emphasise the importance of functionally classified knowledge – and the capability of being able to identify alternative start points. As a consequence of these factors, the ideality tool always encourages the user to think first about the ideal final result (IFR), and to work back wards, rather than the conventional evolution strategy of starting from today's system and projecting forwards.

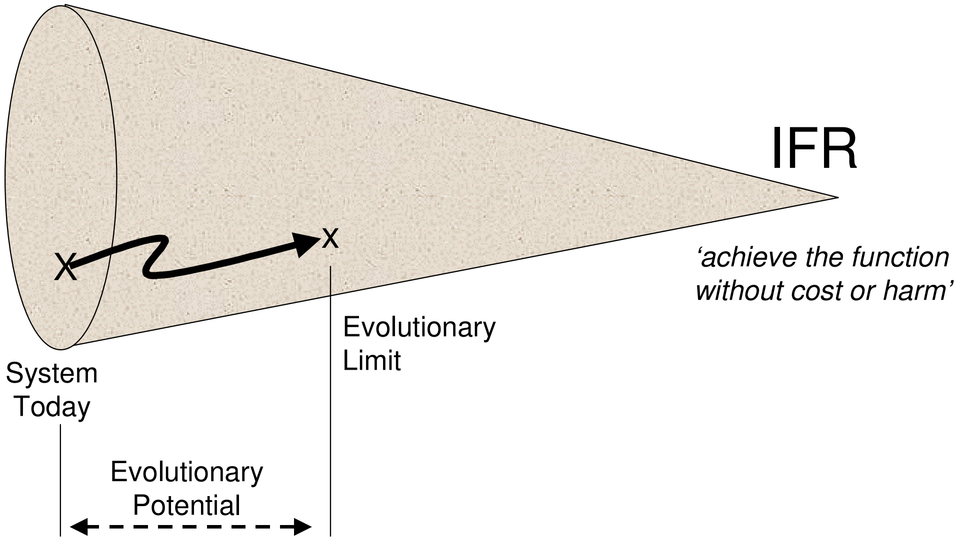

Figure 4: Evolutionary Potential and Limits and Ideal Final Result

If the ‘achieve the function without the system’ concept suggested by the IFR definition sounds rather too abstract when thinking about the ideal final result automobile, it becomes rather more concrete as the focus zooms-in to think about, for example, ideal final result windscreen wipers, or heater fans, or steering wheels or instrument panels. At these component levels, it is highly likely that systems will evolve to precisely the ‘deliver the function without the system’ level described by the ideal final result definition.

The reason for this phenomenon – which is important from the perspective of the theme of this paper – is another fundamental dynamic of system evolution uncovered by TRIZ researchers; that of the migration of function delivery to higher levels in a system hierarchy. The concept is illustrated in simple terms in Figure 5. This evolution direction toward the super-system is a factor that should encourage all designers to take an increasingly holistic perspective on the artefacts they produce. The key question; is there something already in the higher-level system that can deliver the function required by this system? Chances are, the answer will be yes.

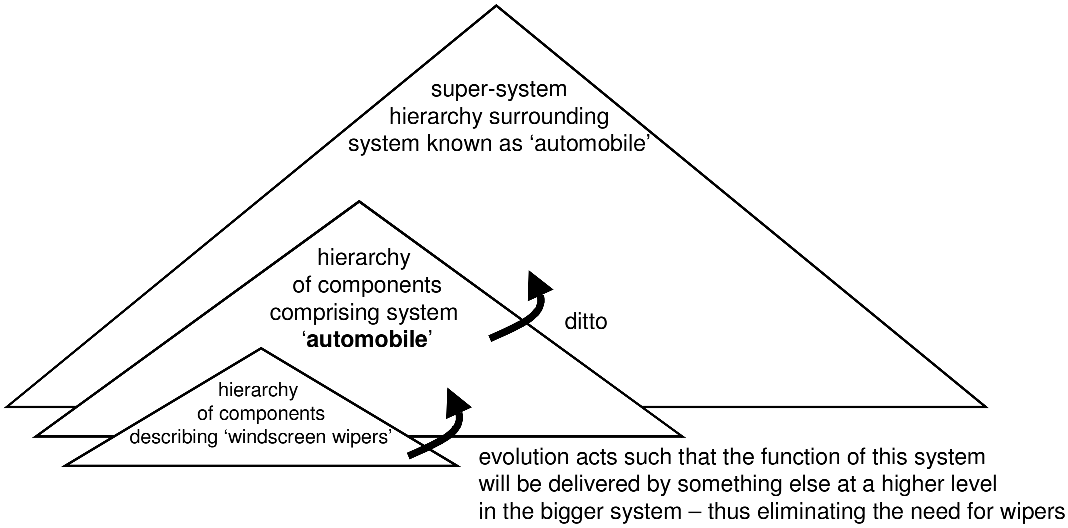

Figure 5: Evolutionary Migration Towards Holistic Definition of ‘System’

Having provided this overview of some of the key elements of TRIZ, the paper now examines exemplar cases of the tools in action; starting at the sub-system and working upwards toward the super-systems surrounding the automobile. All of the TRIZ tools are applicable at each and every system hierarchy level, and so it is important to note that the following cases are merely utilising the tools most suitable to the particular case under investigation.

COMPONENT-LEVEL EXAMPLES

1) Bearing Evolution

Some of the larger implications of bearing system evolution have been discussed in the preceding systematic innovation overview. Evolution of the roller bearing at a more detailed level – as illustrated in Figure 6 – suggests through the use of evolutionary potential radar plots that there is still significant development opportunity for bearing evolution at a more detailed level. This is a subject that has previously been discussed in more detail in Reference 4. The importance in the context of the theme of this paper is that this kind of bottom-up component analysis is something that can be constructed for every other element of the automobile design in order to construct an overall evolutionary potential hierarchy.

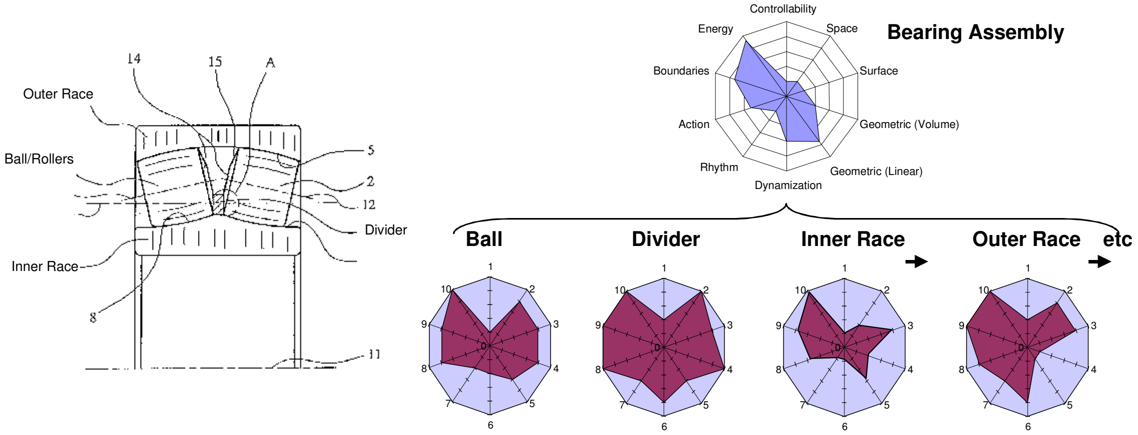

Figure 6: Hierarchy of Evolutionary Potential Plots for Typical Rolling Element Bearing

2) Windshield Buzz and Squeak

Another component-level design problem that has implications for the bigger picture automobile design involves the chosen strategy for joining and sealing transparencies to the bodywork. This problem has previously been used (Reference 5) to highlight the differences between traditional 'design is a trade-off' and TRIZ 'contradiction-elimination' strategies.

In simple terms, the problem designers face in this area can be summarised as *"The moulding lip must not squeak when subjected to small scale random oscillations against the painted body sheet metal and, additionally, the lip must not buzz when presented with any high speed air flow situation likely to occur during usage."* The problem is described graphically in Figure 7.

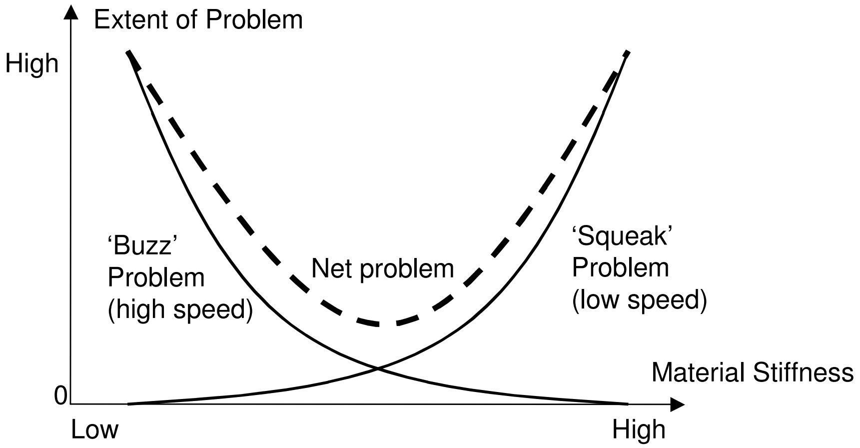

Figure 7: Windshield Buzz/Flutter Physical Contradiction

Traditional design by trade-off practices would cause the designer to 'optimise' the design at the point where the combined adverse effect of the two different problems was at its minimum. This is by no means a bad strategy; although it quite likely results – as it actually did in the Reference 5 instance – in the existence of some buzz and squeak problems at some vehicle operating conditions.

From the TRIZ perspective, the problem highlights a very specific contradiction; the seal lip should be both stiff and flexible. Solving this problem (one which – in generic terms – TRIZ shows to have been solved by many problem solvers already) leads to novel solutions that offer many new opportunities to think about the way glass and metal are joined together in future designs. Reference 5 indicates some of the emerging solutions. One that is not featured in that reference, but may be used to highlight the types of strategy involved in eliminating this kind of 'stiff and not stiff' contradiction, involves a seal design that recognises the two different stiffness requirements occur at two different operating conditions – such that the seal needs to be stiff at high speed conditions and flexible at low speed conditions, or, thinking about it yet another way, it needs to be stiff in regions exposed to the external airflow and flexible at the interface with the glass.

3) Impaction Protection Panels

The design of all automobiles is constrained by a large number of contradictions. Whereas traditionally designers are taught to optimise the way they trade-off between the different conflicting requirements, TRIZ points them towards the solutions of those that have chosen not to accept compromise. By way of a previously unsolved example, it is possible to identify a number of contradictions surrounding the design of vehicle occupant impact protection systems. There is a desire in all cases to improve the strength of such systems. On the other hand, traditional logic dictates that improved strength comes at the expense of weight, construction complexity and a variety of other design parameters. The technical contradiction part of TRIZ points users to the strategies used by others who have sought to improve strength without letting weight or complexity get worse. In fact, the method goes further and suggests that, thus far, looking across over 2 million patents there are just 40 possible strategies for eliminating any form of compromise (Reference 1). To pick one such example, TRIZ shows there to be four commonly applied strategies used to solve strength versus complexity conflicts. One of these, Principle 13, 'The Other Way Around' ('turn the system upside-down or inside- out') presents the idea of novel honeycomb forms – Figure 8 – that can be shown to give distinctly improved impact properties at zero increase in construction or integration complexity. In fact, the 'auxetic' honeycomb form appears to also offer significant advantages when incorporated into curved forms – which in turn presents automobile styling designers with a range of potentially exciting new opportunities.

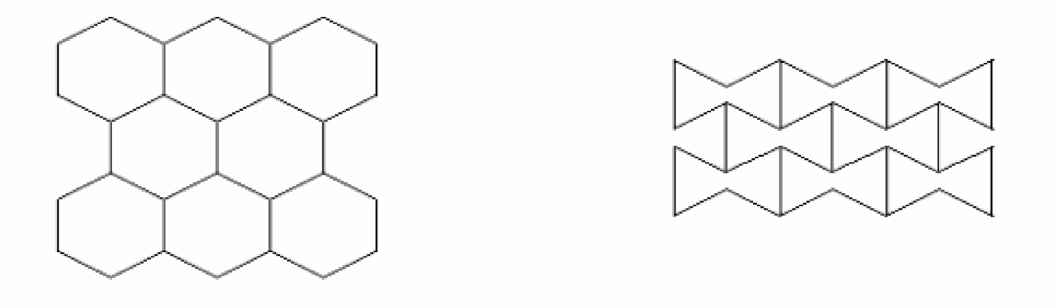

Figure 8: Conventional versus Auxetic Honeycomb Impact Protection Concept

ASSEMBLY-LEVEL EXAMPLES

1) Cabin-Heating

Moving up the hierarchy of sub-systems within a vehicle, an ongoing project is examining alternative means of providing heating systems within the occupant compartment. Heating is conventionally achieved by extracting waste heat from the engine block and pumping it, via a series of tortuous ducts, into different parts of the cabin. The net result is a bulky and expensive system that tends, in most designs, to heat different parts of the cabin better than others. This is an area where it is potentially beneficial to examine other possible means of delivering the heating function. One such possibility may emerge through a novel electrically conducting 'paint' system that may be applied to a variety of different surfaces (including the underside of the carpets) within the cabin to spread the heat sources more appropriately; all the time, thanks to the conducting properties of the paint, without the need for complex wiring looms.

The switch from direct use of waste engine heat to an electrically based system might appear to present a net increase in the complexity of the system. On the other hand, using the functional knowledge base again, but this time applied to the function of 'energy conversion', it is possible to identify the Nernst Ettinghausen Effect as a highly practical means of converting waste heat directly into electrical energy (see Reference 6 for example).

As well as re-enforcing the message about looking outside traditional boundaries for 'good' solutions, the cabin heating problem also suggests the importance of holistic design approaches – where the delivery of different functions is beneficially considered in a combined as opposed to isolated manner.

2) Self-Balancing Systems

The evolution of systems towards an ideal final result in which customer benefits are delivered without cost or harm, points towards solutions that solve problems 'by themselves' (Reference 7). Self-cleaning, self-compensating, self-regulating and self-balancing, etc, are all examples – when applied in their true systematic innovation manner – of objectives designers should strive for when seeking breakthrough innovation.

By way of example, consider the design of wheels. Several compromises exist in the desire to deliver customers a smooth drive. These compromise start with the specification of tight manufacture tolerances on rotating components, and carry on through inspection of those tolerances during manufacture, the need to protect components during transport, the need for unsightly lead weights on every customers wheel, and the creation of a whole 'wheel balancing industry with its own special machinery to re-balance wheels every time a tyre is changed. The customer pays for the privilege of all of these things either directly or indirectly. The systematic innovation perspective on each and every one of these compromises is that the ideal system would have none of them. The ideal wheel balancing system is a wheel that balances itself.

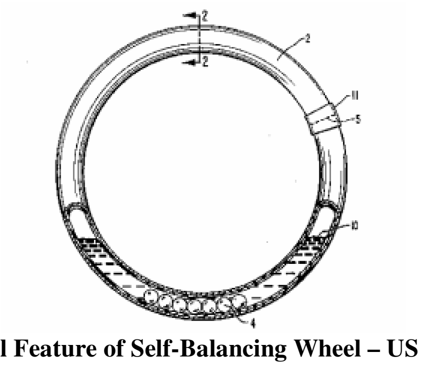

Figure 10: Detail Feature of Self-Balancing Wheel – US Patent 5,142, 936

The implications of the productionisation of such a feature or its relations in other rotatives could be significant in other areas of the vehicle design; not least of which being things like dampers, mounts and component joining methods.

The same self- principle applies, of course, to any other rotating system within an automobile, or indeed any other system (washing machines look set to be the first place where this kind of 'self-balance' capability will enter the market). Any self-balancing rotative will tend to solve a number of design contradictions. The same applies to any other kind of self- delivered function. Others currently under evaluation by this author that may have an impact on automotive design at various levels include self-cleaning filters, self-cleaning transparencies and self-aligning joins.

SYSTEM-LEVEL EXAMPLE – Super-System Effects

According to systematic innovation evolution theory, the functions delivered by the system called 'automobile' will ultimately be performed by something else at a higher hierarchical level. The corollary to this, however, is that the automobile could take on some of the functions currently being delivered by other systems. This shift in thinking is likely to be particularly interesting in the context of discriminating one vehicle design relative to another. Automobiles are currently designed to deliver the function 'transport occupants from A to B'. Every automobile is capable of delivering this function very well – to the extent, in fact, that it is often very difficult for the consumer to discriminate between different products.

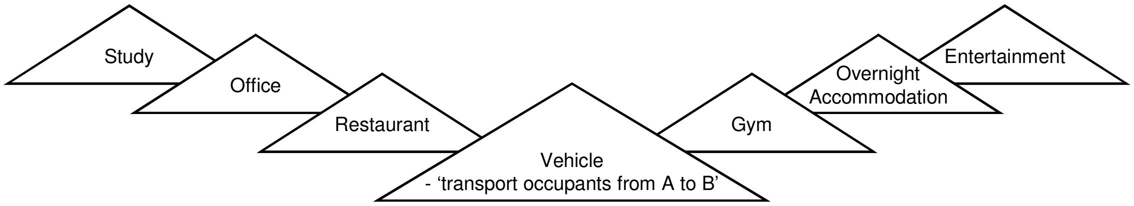

Figure 11: The Automobile as a Component Within an Array of Higher Level Systems

The office offers a potentially interesting example of this 'taking on the function of other things' process in action. When asked what the office of the future would look like, management guru Tom Peters purportedly answered 'what office?'. The truth of his speculation is rapidly becoming apparent in a number of 'hot-desking' organisations. So could the automobile begin to take on some of the useful functions of the office? If the industry starts to think more holistically, the answer must be a resounding yes.

Some of the business-oriented trends contained within the TRIZ framework may further serve to expand the scope of evolution directions of future automobile designs. One such trend is the 'customer expectation' trend illustrated in Figure 12. This is a trend first discussed in Reference 8.

Commodity Based Economy ➡ Product Based Economy ➡ Service Based Economy ➡ Experience Based Economy ➡ Transformation Based Economy

Figure 12: Customer Expectation Trend

The most significant aspect of the trend as far as automobile design is concerned is the shifting emphasis of customer expectations from thinking of the car as a ‘product’, to a service (indicative of sale models in which the customer actually buys the function rather than the vehicle – as in power-by-the-hour jet engines and contract carpeting), to – rather more interesting from a vehicle design perspective – an ‘experience’. The design of automobiles as experiences could represent a whole new paradigm in the not too distant future.

SUMMARY AND CONCLUSIONS

As systems mature they begin to hit fundamental limits. Fundamental limits give rise to design solutions that require ever-greater levels of effort to produce ever-smaller benefits. They also produce solutions that increasingly converge on a norm. Every component within a car as well as the car itself is subject to the emergence of these fundamental limits. Systematic innovation research has uncovered the mechanics of breakthrough innovation. The paper has demonstrated how some of the tools, methods and strategies developed during the research can be applied to generate breakthrough innovation concepts at component, assembly and overall system level.

At the overall system level, future innovation of the automobile – which in many senses is becoming commoditised in the current business concept paradigm – needs to look beyond just the automobile. Breakthrough innovations in overall business concept – services, experiences, etc – may well be more important than purely technical design considerations.

At the sub-system level, there is still significant untapped evolutionary potential in the large majority of components and assemblies found in the car, and thus large scope for breakthrough innovation. The focus for such innovation – whether that be cost reduction, reliability improvement or generation of new functionality - must be driven by super-system level business model innovation.

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