

Evolutionary change in automotive technology : long term developments, artefacts, producers and consumers

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Evolutionary change in automotive technology: long term developments, artefacts, producers and consumers.

Jena, Germany, October 18-19, 2007

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Abstract

Explaining technical change can be done by using (evolutionary) economic arguments such as path dependency, lock in and paradigms. However I argue that for a better, more enriched, picture of technical change quantitative data falls short and qualitative sources are essential for understanding technical change. The actual practices of producers but also of consumers play an important role in the explanation of technical variety. For example, the co-existence of several types of different engines (Diesel, Otto, Wankel) can not only be understood by looking at the mere technical data and economic reasoning, but have to be explained by looking at consumer behaviour and choices that not need to be rational.

In this paper I will make an analysis of technical change in automotive technology by looking at changes at the artefact level of the automobile which should be considered as a complex technical artefact consisting of a number of systems, subsystems and components, which work together to afford certain kinds of functions. The focus here will be at the engine capacity and engine power. The goal is to explain technical change by analyzing the technical data for a long period.

1. Introduction

The automobile is a technology that has changed society dramatically over the last century. But not only society changed, the technology of the motorcar itself has changed significantly: an automobile of the 1900's has almost only the concept of four wheels and an engine in common with today's modern cars. The academic world has given little attention to the history of the car, but the last couple of decades the body of literature is growing. Still there is little attention to the technical history of the motorcar itself.

In this research the artefact is the object of research. Studying the technology of the motorcar raises a number of different problems. First there is the complexity of the artefact. A motorcar consists of a complex structure of a large number of components that work together in different systems and groups. To study changes in all appropriate levels a systematic approach is needed to keep track of developments in different areas. Second problem in studying historical car technology is the size and variety of the population. Not only have there been hundreds of millions of cars produced in the period 1885-1980, but also a great number of different types of which the properties vary to different extents. But the main problem and therefore the main theme in this research is the link between the car as a technological artefact and its role within society. The question is how to link technical properties to user functions and the use in the real world.

This research starts from the basic viewpoint that technology has a dual nature: it contains an intrinsic power to shape the future path of development, but also is submitted to external forces that create or limit new developments. For analyzing long term developments in automotive technology I will introduce a framework that includes ideas on technical change from evolutionary economics, such as trajectories, path dependency, dominant design and technical paradigms.

Automakers tend to make consumers believe that every new model they introduce is "new" and "revolutionary", both in terms of design and technology. However when one looks at the actual changes, 'progress' in automotive technology is rather limited and slow. It's often argued that the last major innovation was either the air-conditioning or the automatic gearbox; innovations that both date back to the 1950's.

In the first part of this paper I will shortly deal with some relevant theories on the topic of technical change with the focus on the automotive industry followed by an exploration of a theory of technical change in terms of radical or incremental change. In part three I will discuss some specific problems of studying the motorcar in history. In the next part the data for the case here, engine size and engine power of cars on the market in The Netherlands 1950-1980, will be discussed, as well as some preliminary analysis of the data. In the final part I will propose a framework for explaining technical change based on the 'Dual Nature' principal and I will raise a number of questions that can be dealt with using such a framework.

2. Theory of technical change in automotive history

Technological change has been the field of study for more than seventy years now. Technology has been studied from several different directions, but mainly from an economical perspective because technology is seen as the driving factor behind economic growth. In the 1970's however technology as a theme of study has also come under the attention of sociologists, philosophers and historians. One of the main questions in this emerging field of Science and Technology Studies is how technological change occurs. What causes technical change? Overtime two different main directions of explanations for technological change have emerged.

First is Technological Determinism, best expressed by the work of Lewis Mumford.¹ The premium assumption of Technological Determinism is that technology has its own intrinsic power that steers the direction of future developments. Opposite to this view the SCOT (Social Construction Of Technology) approach emerged in the late 1970's and beginning of the 1980's.² SCOT emphasizes the role society, existing out of different groups with different powers, plays in the development of technology. The opposition between Technological Determinism and SCOT has many forms and gradations. The polarized difference between the intrinsic power of technology versus the external or contextual powers are expressed differently in different fields of technology and therefore have a broader scope than simply the Science and Technology field. In studying history of technology it makes sense to at least beware of this ongoing discussion to analyze technical developments.

This research will continue from the basic viewpoint that technology has a dual nature: it contains an intrinsic power to shape the future path of development, but also is submitted to external forces that create or limit new opportunities. Furthermore the two discussions in the field of history of technology will serve as a theoretical background. Technological determinism versus Social Construction of Technology and Narrative history versus Theoretical history are interesting oppositions for further research. The hypothesis is that both are extreme oppositions and the best view lays somewhere in the middle. But this is of course oversimplified. The main purpose is to understand more about technical change on the artefact level and the discussion will be kept in mind in looking into the technical specifications of the artefacts.

All three layers (artefacts, human activities and knowledge) of technology as introduced by Bijker (1995) will be studied. The artefacts will be the automobiles and there technological components. For studying the artefacts a structural model as developed by Gijs Mom will serve as a tool to analyze technological change on different levels (see figure 2.1). The second layer (human activities) is the broadest and will involve the engineers and users of the

¹ See for instance the works: Mumford, L. (1963). *Technics and civilization*. and Mumford, L. (1967). *The myth of the machine*.

² See for examples of SCOT theory the *Handbook of science and technology studies*. By Jasanoff, S., Markle, G. E., et al. and the work of Wiebe Bijker

technology. In the case of the car, the users are of course the drivers and passengers, but also people who are affected by cars. Although it is not the idea to explain how automobiles have changed the lives of people in general (I would suggest to read Flink or Sachs), it is important to look at users and non-users to investigate motives for technological changes. The knowledge about automobiles, in a large variety of forms (books, papers, tacit, manuals) is also shared by users and non-users. In this case users are not merely car users, but more car engineers; people who are involved in technological developments of cars.

The three levels of technology corresponded partly with three other levels of analysis: artefact, system and society. Here the main focus is upon the artefacts, but this study also tries to make a link with the car as a system and the role of automobiles in society. An automobile is a complex structure of components varying in complexity and dependency. Studying technical change in automotive technology requires a hierarchical structural model that makes it possible to analyze changes on different levels. The model used here is developed by Gijs Mom and it consists of a hierarchical division on the level of artefact, subsystems, main functional groups, auxiliary functional groups, component assemblies and basic components (figure 2.1).

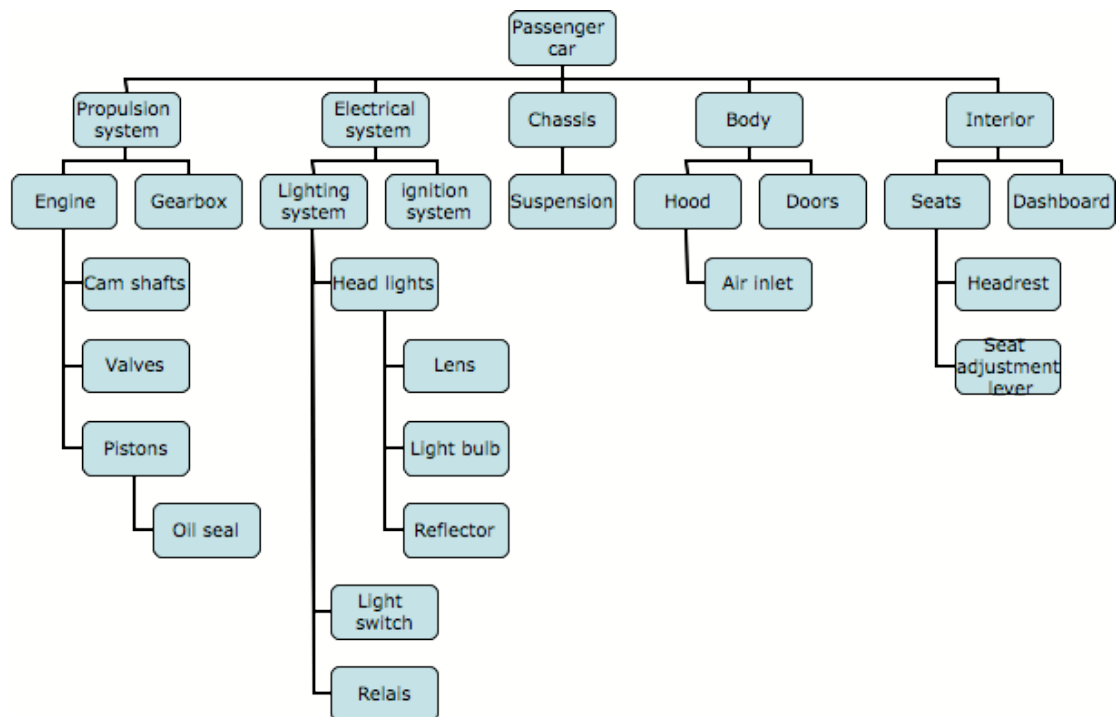


Figure 2.1: A structural model for analyzing automotive technology.

The artefact here is a passenger car that has a propulsion system (subsystem) that consists of a number of parts. For instance the engine and gearbox (main functional group) with a gear system (auxiliary functional group)

and synchromesh (component assembly) and finally a number of nuts and bolts (basic component).

The argument is that changes can occur on different levels of the structural model and these changes differ in impact they have on other components, the artefact as a whole and on society. Using this particular model will give insight in the nature of technological change by showing not only the important revolutionary changes, but also the small evolutionary developments. In fact the assumption here is that most revolutionary changes start as a small change on a lower level and thus could be called an evolutionary development. The level of analysis in this part of the research is the automobile as an artefact.

In his book *The productivity Dilemma* Abernathy puts the theme of innovation in automobile technology in the perspective of production factors.³ Basically he argues that the automotive industry has grown to such a proportion major innovations do not take place anymore since the Second World War, as these innovations would be far too costly to implement in the whole production process. His focus is mainly on the American automotive industry where indeed the production process causes inflexibility in design options. However, in Europe and especially in Japan other production methods have led to different design processes, allowing more innovation. So the question how much innovation really happens in the automotive industry is still relevant. Especially when we attempt to describe these innovations in terms of radical or incremental.

Artefacts consist of a nested hierarchy of subsystems, although there has not been sufficient attention to this in empirical research on dominant design, some however do. Henderson and Clark distinguish between incremental, modular, architectural and radical innovations.⁴ The hierarchical structure has an important implication: a modular change at one level in the hierarchical system can be an architectural or radical change at a lower level in the hierarchy..

³ Abernathy, W. J. (1978). *The Productivity Dilemma. Roadblock to innovation in the automobile industry*. Baltimore London: The Johns Hopkins University Press.

⁴ See: Henderson, R. M. and Clark, K. B. (1990). "Architectural Innovation: The Reconfiguration of Existing Product Technologies and the Failure of Established Firms." *Administrative science quarterly*, Vol. 35(1): pp 12.

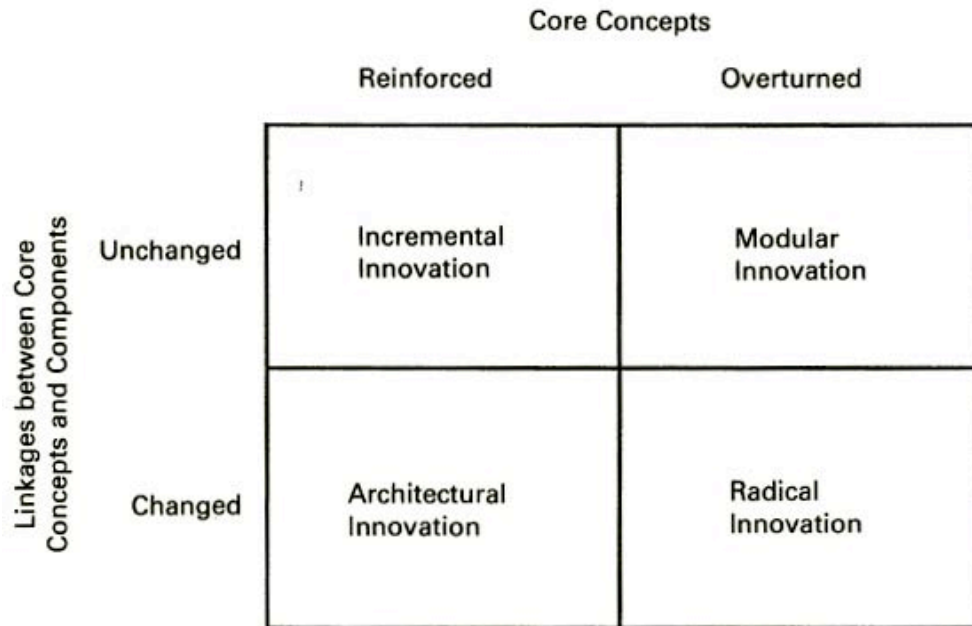


Figure 2.2: A framework for defining innovation. Source: Henderson, R. M. and Clark, K. B. (1990). "Architectural Innovation: The Reconfiguration of Existing Product Technologies and the Failure of Established Firms." *Administrative science quarterly*, Vol. 35(1): pp 12.

The concepts used by Henderson and Clark proves to be useful in analyzing automotive technology. The concepts can be coupled to specific levels in the automobile as an artefact (described in figure 2.1), where the architecture could be a change in vehicle platform (the basis of a motorcar, consisting of its underbody construction), the modular level can be compared with e.g. a engine or gearbox and incremental level can be any small change. What an radical innovation would be remains the question, because on this level the step from the horse drawn chariot to the automobile would be the last radical change that occurred.

Peter Hugill goes into the architectural innovation of the automobile in his analysis of drive systems.⁵ Hugill defines the placement of the engine, transmission, driveshaft and final drive as the main characteristic of an automobile (See Appendix A). By using these limited amount of components he is able to track the major innovations in 100 years of automobile technology as they are simply coupled to the variations of placing the core components. Problem however is that all incremental changes are overlooked and thus this analysis has rather limited explanation power. For instance the Issigonis/Christie system (Appendix A, figure A11) would not have been a technical possibility without developments that allowed engineers to limit the size of the engine and gearbox. This system was used in the famous Mini of the British Motor

⁵ Hugill, P.J. (1988). Technology Diffusion in the World Automobile Industry, 1885-1985. In: Hugill, P.J. & Dickson, D.B. (1988). *The transfer and transformation of ideas and material culture*. Texas: Texas A&M University Press.

Corporation (BMC) from 1960-2000.⁶ For a further explanation on technical change we need to look beyond these general architectural concepts and look at incremental changes as well. Before doing that I will discuss some problems that one runs into while researching automobiles in history.

3. The car as artefact, problems and challenges

For analysing the history of the automobile a periodization is needed, as well as a geographical boundary. The larger research project to which this paper belongs deals with changes in automotive technology from 1885 to 1980 and is basically concentrating on Western Europe (France, Germany, The Netherlands and Italy), although comparisons will be made with other continents.

The date of birth of the motorcar is a point of discussion. Some would argue that the steam car built by Cugnot in 1770 was the very first automobile while others say that the Benz tricycle of 1885 was the first motorcar. The discussion depends on the technology that defines a motorcar. The Cugnot vehicle was driven by a steam-engine. Steam technology as a means of transportation has been around for a long time since then and the development of the internal combustion engine was at least for some part based on knowledge derived from steam technology because both types of engines used the same principles. High pressure, pistons and axles were all elements that could be found in steam-engines and the first internal combustion engines. One of the key-players in the development of the internal combustion engine was Ettiene Lenoir, who made an internal combustion engine that resembled a steam engine in design and operation, but he only saw industrial purposes for his engine. His concept was improved by Otto, who came up with the four-stroke principle. Both Gottlieb Daimler and Karl Benz used the Otto design to build a motorized vehicle around 1885. Their effort is most commonly accepted as the birth date of the automobile, but the evolutionary development of the engine should not be lost out of sight.

The timeframe is divided in three periods, as sociologist David Gartman does in his article 'Three Ages of the Automobile'.⁷ The division in periods is based on the cultural meaning of the motorcar in different eras. Expressed in years these periods roughly correspondent to 1885-1918, 1918-1958 and finally 1958-1980. In the first period, the automobile is a luxury good, affordable to only a limited number of people. In this early period an enormous variety in technological options existed. In the second period, the technological variation decreased, but competition on the market became more severe. Manufacturers sought for means to differentiate their products from the competition, either by design or by technological developments. The last period is the era of mass motorization (of Europe). A whole new range of consumers with different needs

⁶ Georgano, G. N. and Andersen, T. R. (1973). *The complete encyclopedia of motorcars : 1885 to the present*. London: Ebury. Pp. 498.

⁷ The article 'Three Ages of the Automobile' was published in a special issue on cars and society of *Theory, culture & society : explorations in critical social science*.

and desires were able to afford motorcar, which was reflected in both design and technology. The end date of the population demarcation is more or less subjective. But 1980 has been chosen because at that point a new era starts with the growing of importance of electronics in automobiles. A development that is still taking place today.

What is an automobile? The definition of this technical concept is not without problems. An automobile is at least a vehicle with wheels and a source of propulsion. The question is what types of vehicles should be included or excluded here. Is a car with three wheels still a car? The source of propulsion, should it only be petrol, or also electricity and steam? When does a car become a truck? In defining the car, some anticipation on the future research is needed. General definition: A car is a vehicle with at least three wheels that has its own propulsion source. Definition considering the developments in history: A car is a vehicle with three or four wheels, generally with air filled tires that runs on petrol, gas, electricity, steam or another type of fuel. A car has a steering system for changing direction and a braking system for lowering the speed. Along this definition there is something like 'the ideal car'. For instance the Rolls Royce Silver Ghost at the beginning of the twentieth century had all the qualities that an owner or driver could wish for. However with the growing variance in user forms (touring, racing, holiday, commuting etc.) the car became more and more a compromise of different properties for different types of use. 'The ideal car' changed in time, in space and was varied for different groups of user. Besides the ideal car, there is a existing 'archetype car', expressing the general picture of the state of technology on a certain point in time (e.g. Ford Model T) and a non-existing 'average type', which is the sum of all technical possibilities divided by the numbers they exist in reality.

But besides a definition on the car on technical properties it is also possible to define a motorcar using a different language. From a cultural sociological point of view the car can be defined as a symbol that people use to make a statement about their lifestyle. By defining a car as a means of expression the analysis of the relation between people and cars, and thus between people and technology receives another dimension. Furthermore it becomes clear that different groups of people have a different view upon cars, even one single person can change its view overtime, but also levels. A single car user normally doesn't view upon himself as a polluter or killer, but without any doubt the car system pollutes the environment and kills a large number of people each year. The same goes for congestion: one person doesn't cause traffic jam; all the other people cause it. This variance in opinions should be noted here, because it also influences the technological development of motorcars, which as stated earlier are partly an expression of wishes and dreams of consumers. Cars have become the fulfilment of a dream of freedom, but it is questionable whether this dream has been fulfilled, or even will turn into a nightmare

There are three levels of analysis to be considered here. First there is the artefact, which is studied using the hierarchical model. Then there is the population in which the focus lays upon the spread of changes throughout the

total population of motorcars. Third level is the socio-technical context in which the artefact has its relations with different types of actors. In using this three-level approach a history of automotive technology is written, but furthermore the goal of this study is to bring back the real-life technology into the field of socio-technical studies.

The main research question on the first level, the artefact, of study is what the most important technical changes were in automobiles over the three periods and how they occurred. On the level of the population of automobiles, the European car market, the main question is how the technological changes diffuse within the population. This should give more insight in the processes that steer technical developments. Last question focuses upon the interaction between technology and society and the places where these entities meet. Technologies are the expression of wishes, ideas and desires of people whom life in a group, a society.

To put it briefly, the history of the automobile has many stories to tell, so it's important to stay on track. When we just look at the history of the artefact expressed in technical data, there are a few practical problems as well. Most important problem is the sources, especially for the period before the Second World War. The technical data that can be found in journals in the Pre-War period is often incomplete and not yet 'standardized'. It is hard to retrieve a homogenous set of data on technical properties in time, but also in space. Different countries used different measurements, but also different specifications (often based on the local system of taxation). Another issue for further analysis is the lack of reliable sales numbers of makes and models for the early period, as these were only recorded systematically in most countries from the Fifties onwards. One final problem is the sheer variety of technical components that have been and are being used in automobiles. To illustrate that there is a list of contemporary car types in Appendix B. Similar lists could be made for body types, chassis types, engine types and so on. One of the challenging and interesting issues about automotive technology that it gives both examples of substitution technologies, but also co-existence and co-evolution of competing technologies (e.g. different engine types: Otto, Wankel, Diesel).

4. Data: engine size and horsepower 1950-1980

The main analysis in this paper consists of data for cars on the European Market in the period 1950-1980. The data used is derived from catalogues and automotive journals, which are also used as qualitative sources for consumer behaviour. Finally engineering journals and conference proceedings are used to research producer behaviour.

The importance of the specific period 1950-1980 is shown in figure 4.1:

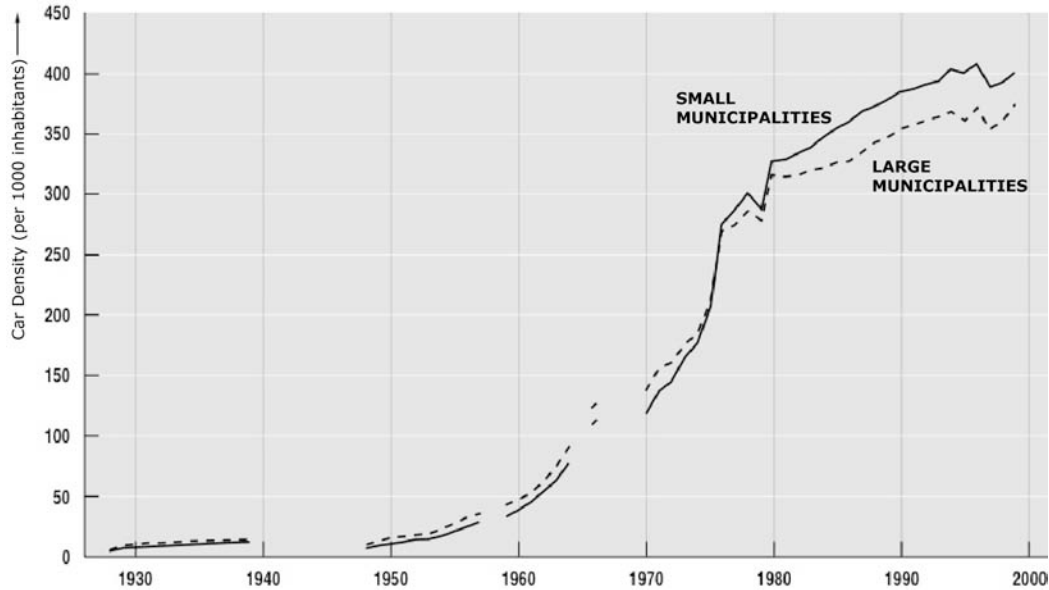


Figure 4.1: Car Density in the Netherlands. Source: based on Staal, P. E. (2003). *Automobilisme in Nederland : een geschiedenis van gebruik, misbruik en nut*. Zutphen: Walburg Pers. pp.47.

It is clear to see the rapid growth of density of cars per inhabitant in The Netherlands in both large and small municipalities for this period (the graph is based on a study of diffusion of the motorcar in The Netherlands). Such a rapid growth could well imply some major changes in the technology, as a great number of new users start to adopt the automobile.

The following data on engine capacity was taken from yearbooks for each second year (1960, 1962, 1964 and so on) that contains prices and technical data of all the vehicles available on the Dutch market.⁸ For each specific model an average type was chosen, as some car models are available in different configurations. For instance a Golf Mark I was available as a 1100, 1300, 1500, GTI and 1600 Diesel version, with L, S or LS specifications. In this case all the different engine variants are included, but leaving the trim level (L, S or LS) out of consideration.⁹

⁸ 1950-1966: *Jaargang van catalogusprijzen van automobielen en motorrijwielen*. 1966-1980: *Kies uw Auto: KNAC auto jaarboek*.

⁹ For the technical property engine capacity this remark is less relevant, but for instance 'weight' there can be differences in the type of model that is chosen, as luxury always adds weight to a car.

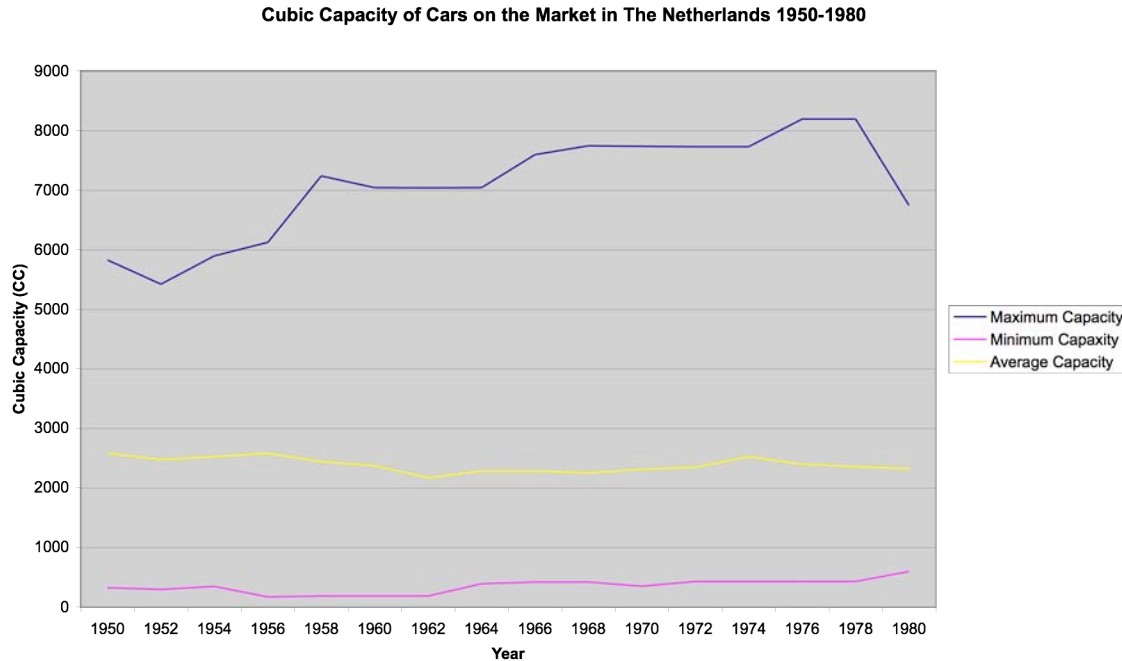


Figure 4.2: Cubic capacity of cars on the market in The Netherlands 1950-1980

The graph shows some distinctive developments. The average engine size of cars on the market in The Netherlands is floating between 2 litres and 3.7 litres, which is quite large. This is caused by the relatively high number of American automobiles that were sold in The Netherlands, a long-standing tradition dating back before the Second World War. The rapid growth of the maximum engine size in the late fifties can also be explained by the growth of American cars in both vehicle size and engine size. The period from halfway through the fifties until the beginning of the sixties which show a drop of the minimum engine size can be explained by the a number small engined vehicles from Eastern Europe.

One of the biggest problems in making an analysis is the lack of concurrent sales data that specifies the make and model for each year. Only from the seventies onwards these figures were documented in The Netherlands. Figure 4.3 shows the minimum, maximum and average horsepower of the 20 best selling cars in The Netherlands. From 1970 onwards these are based on actual sales numbers, but earlier figures are derived from journal articles and loose information in yearbooks.

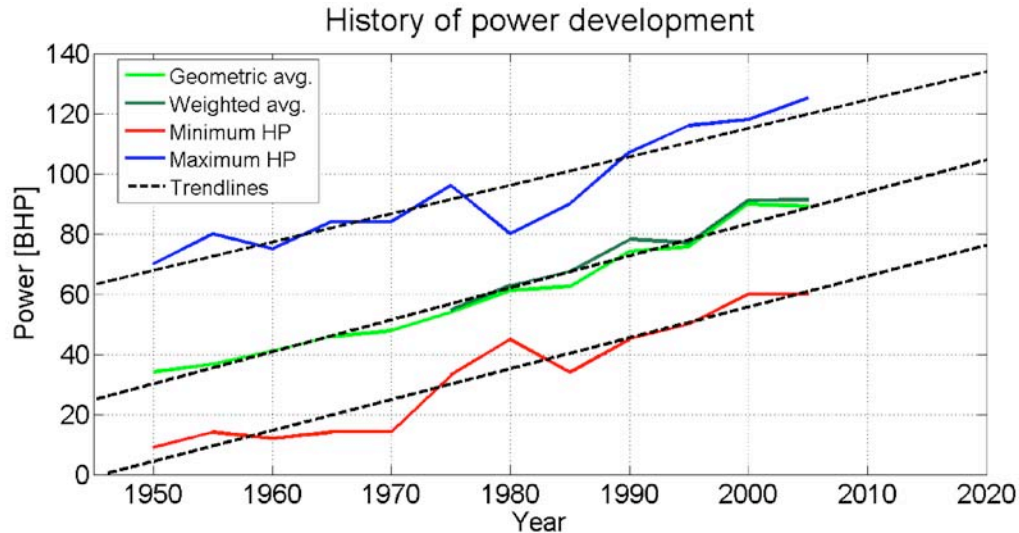


Figure 4.3: Development of horsepower of the 20 best selling cars in The Netherlands. Research conducted by engineering students for the course Autotrends 2007.

It is clear that the maximum, minimum and average power of the 20 best selling vehicles in The Netherlands went up during the period 1950-2020, although we can see some variance in the figures. The drop after halfway through the seventies in maximum engine power could easily be coupled to the oil crises in that period, but this drop has no significant meaning for the average power of the best selling vehicles. The maximum and minimum are however slowly closing up to each other when one looks at the trend lines.

The two graphs are not fully comparable, but they do however raise a number of questions. We can assume from both graphs that engineers were able to retrieve slightly more horsepower from the same engine size. The engine size tells a lot about the characteristics of an automobile. Coupled to the horsepower it could be used as an efficiency measurement of developments in engine technology. So the engines became more efficient, but we need to look deeper into the technology to see why this could happen. New technologies like turbochargers, superchargers and improvements in fuel quality may well have contributed to this development. So we need to analyse the work of the engineers some further and with different, more qualitative, tools.¹⁰

5. Conclusion

A car is an artefact that consists of a complex hierarchy of different components and that is used in a specific context. Some components change over time, the hierarchical value changes, and the context changes, while other components remain the same or are rediscovered after a few years time. Analyzing this world of changes is difficult but with the help of the structural model and concepts of change like radical and incremental change, it should be possible to investigate

¹⁰ It would also be an idea to analyze this issue with more quantitative data, but for the enormous amount of variety in technical components this is not always feasible.

the nature of technical change in automotive history and technological change in general.

For explaining technical change in general, without only putting up narratives on engineering or artefact histories, the challenge is to work systematically to cover as much ground as possible. For this a model or scheme can be useful to keep track of all the developments and relations that surround the technical artefact. In figure 5.1 such a framework is shown.

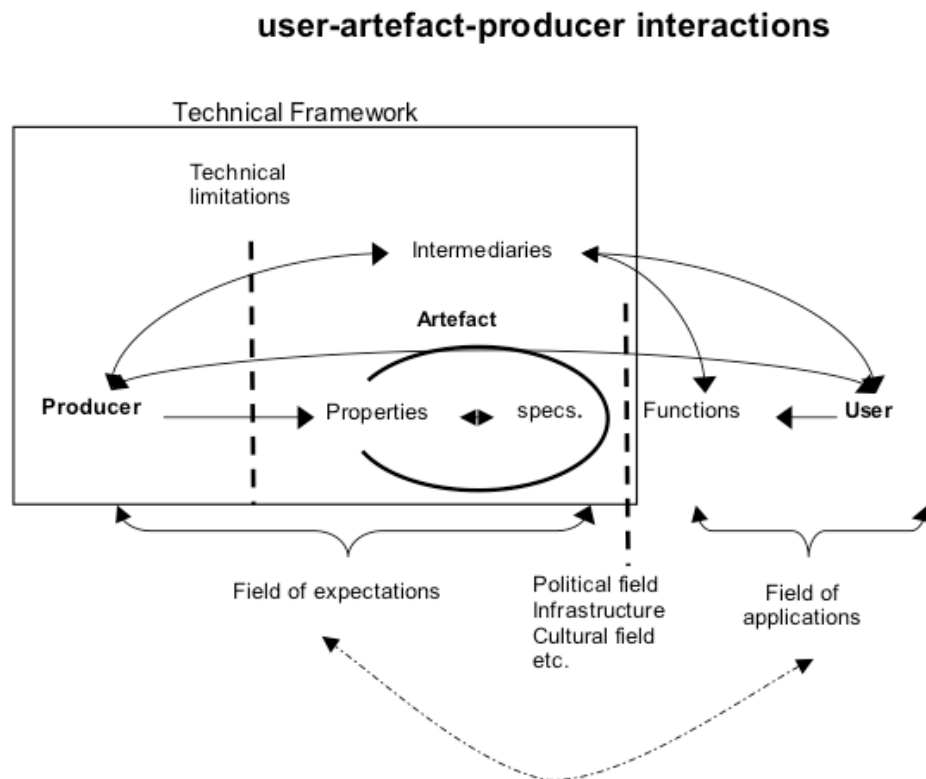


Figure 5.1: A scheme for analysing user-artefact-producer interactions.

This framework allows us to study both the production side of the artefact and the use side. As one of the assumptions is that users have a lot of influence on the design of an artefact, either directly or through mediating agencies. The application (the use) and the expectation (the pictured use) are both strong driving forces for engineers to work on new technologies, which they express in the properties of the artefact. They do this through routinized processes, or by breaking through these processes, which we can call practices. The same goes for users. In the simplified scheme (figure 5.2), the importance of practices is more put forward.

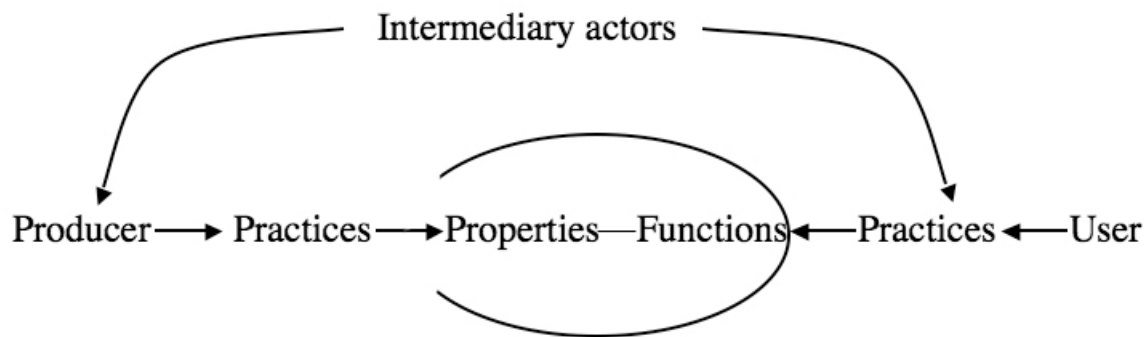


Figure 5.2: A simplified scheme for Producer-artefact-user interaction

The next step is to try to put this schemes to work in a number of case studies partly derived from analysis of the technical shown in part 4 (the European car, shock absorbers) and partly taken from some general developments in the automotive culture (the safety debate and the car as consumer good/symbol).

What is gained by more understanding of change in automotive technology? First of all, a gap in the existing knowledge and literature will be filled. Second, a general knowledge of the past can help to understand more about current and future developments. It is possible to prevent mistakes in development processes by comparing and understanding at similar processes in the past and projecting them to the future. The possible adoption of hydrogen cars is an interesting case in that respect, as it shares some similarities with the steam cars and gasoline cars competition. Third point is more general as this research tries to contribute to the history of technology as an academic field by jointly studying society and technology thoroughly and try to link the two of them on different levels. So this research aims further than merely show developments in automotive technology, it also tries to explain historical developments in society and show patterns of technological development in general.

6. References

- Abernathy, W. J. (1978). *The Productivity Dilemma. Roadblock to innovation in the automobile industry*. Baltimore London: The Johns Hopkins University Press.
- Bijker, W. E. (1995). *Of bicycles, bakelites, and bulbs : toward a theory of sociotechnical change*. Cambridge, MA [etc.]: MIT Press.
- Day, J. and Mech, M. I. (1975). *The Bosch book of the Motorcar. Its evolution and engineering development*. London Glasgow: Collins.
- Flink, J. J. (1988). *The automobile age*. Cambridge, Mass.: MIT Press.
- Frenken, K. and A. Nuvolari (2004). "The early development of the steam engine: an evolutionary interpretation using complexity theory." *Industrial and corporate change* 13 (2): 419-450.
- Gartman, D. (1994). *Auto opium : a social history of American automobile design*. London New York: Routledge.
- Gartman, D. (2004). "Three Ages of the Automobile." *Theory, culture & society : explorations in critical social science* 21(4): 169-196.
- Georgano, G. N. and Andersen, T. R. (1973). *The complete encyclopedia of motorcars : 1885 to the present*. London: Ebury.
- Henderson, R. M. and Clark, K. B. (1990). "Architectural Innovation: The Reconfiguration of Existing Product Technologies and the Failure of Established Firms." *Administrative science quarterly*, Vol. 35(1).
- Hugill, P. J. (1988). Technology Diffusion in the World Automobile Industry, 1885-1985. In: *The transfer and transformation of ideas and material culture*. P. J. Hugill and D. B. Dickson. Texas, Texas A&M University Press: 110-142.
- Jasanoff, S., Markle, G. E., et al. (1995). *Handbook of science and technology studies*. Thousand Oaks, Calif., [etc.]: Sage.
- Mom, G. P. A. (2003). Conceptualising technical change: alternative interaction in the evolution of the automobile. In: *Tackling Transport*. H. Trischler and S. Zeilinger. London, Science Museum. 3: 9-46.
- Mom, G. P. A. (2004). *The electric vehicle : technology and expectations in the automobile age*. Baltimore: Johns Hopkins University Press.
- McShane, C. (1994). *Down the asphalt path : the automobile and the American city*. New York: Columbia University Press.
- Mumford, L. (1963). *Technics and civilization*. San Diego etc.: Harcourt Brace Jovanovich.

Mumford, L. (1967). *The myth of the machine*. New York: Harcourt Brace Jovanovich.

Staal, P. E. (2003). *Automobilisme in Nederland : een geschiedenis van gebruik, misbruik en nut*. Zutphen: Walburg Pers.

Vincenti, W. G. (1990). *What engineers know and how they know it : analytical studies from aeronautical history*. London: Johns Hopkins University Press.

Womack, J. P., Jones, D. T., et al. (1991). *The machine that changed the world : how Japan's secret weapon in the global auto wars will revolutionize western industry*. New York, NY: HarperPerennial.

Appendix A

Architectural innovations: 6 different drive systems. Source: Hugill, P. J. (1988). *Technology Diffusion in the World Automobile Industry, 1885-1985*. In: *The transfer and transformation of ideas and material culture*. P. J. Hugill and D. B. Dickson. Texas, Texas A&M University Press. pp. 110-142.

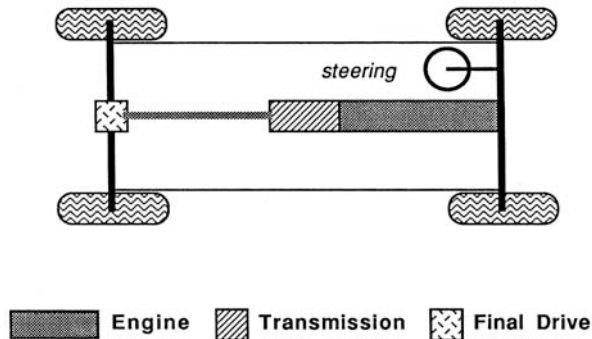


Figure A2. The système Panhard

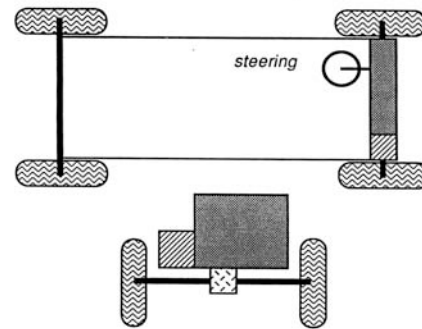


Figure A3. Christie's Front-Wheel Drive

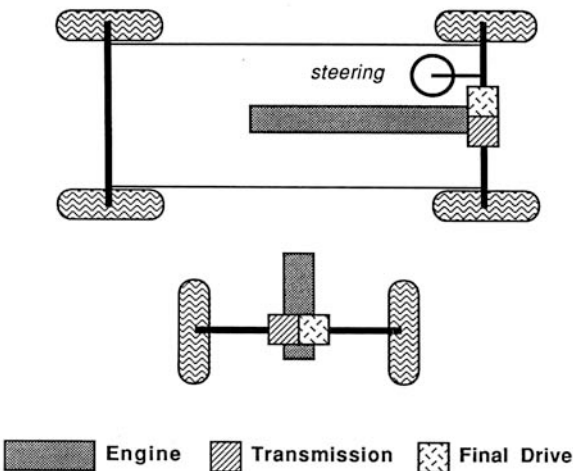


Figure A4. Miller's Front-Wheel Drive

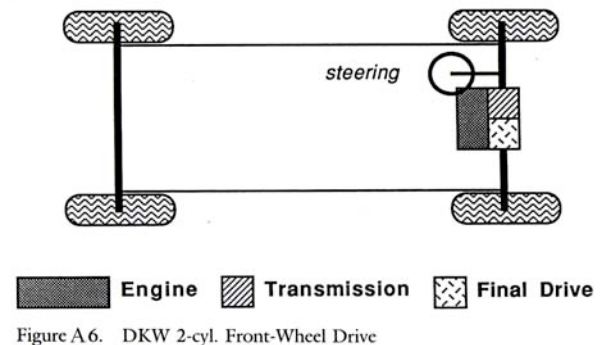


Figure A6. DKW 2-cyl. Front-Wheel Drive

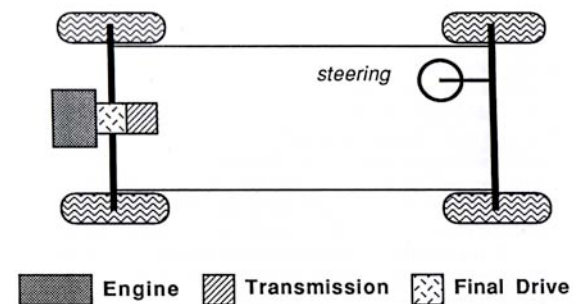


Figure A9. Ledwinka/VW Rear-Engine/Drive

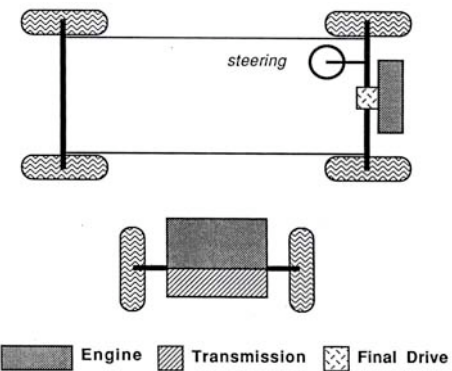


Figure A11. Issigonis/Christie Front-Drive System

Appendix B

Contemporary Car types

Hatchbacks	Crossover SUVs
City cars	Compact crossover SUVs
Superminis	Mid-size crossover SUVs
Small family cars / Compacts	Full-size crossover SUVs
Family cars / Sedans	SUVs
Small family cars / Compact cars	Off-roaders
Large family cars / Mid-size cars	Compact SUVs
Full-size family cars / Full-size cars	Mid-size SUVs
Executive cars / Luxury cars	Full-size SUVs
Small executive cars /	MPVs / Minivans
Compact luxury cars	Mini MPVs
Mid-size executive/luxury cars	Compact MPVs
Full-size executive/luxury cars	MPVs
Stationwagons	Minivans
Pick up truck (truck)	Sports and GT cars
	Coupés
	Cabriolets / Convertibles
	Roadsters
	Supercars