“Introducing a systemic innovation characterized by network externalities: the case of The Whisper”

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In order to finish my master Business Administration, master track Innovation and Entrepreneurship, a research on the introduction of a systemic innovation characterized by network externalities is conducted. The process of this master-thesis provided the opportunity to put the theoretical background gained into practice.

As many fellow students will agree, writing your master thesis is a process of many ups and downs, but in the end it provides a worthwhile experience. Establishing this thesis would not be possible without the help of others. Erwin Hofman and Holger Schiele, supervisors at the Twente University provided valuable guidance and feedback. Also thank goes out to all the participants of the interviews for cooperating in a most benevolent way.

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While a period of student comes to an end, it is fortunate to start working on a professional career. A career which hopefully will bring a lot of learning experiences and theory put into practise.

Didam, July 2011

Executive Summary

This report discusses the details of conducting a case study, The Whisper Bus, on introducing a systemic innovation characterized by network externalities. The purpose of this research was to identify the critical factors and preconditions that ensure the introduction to succeed. It is hoped that the findings will illustrate these critical factors and preconditions, which in-turn will lead to improvements in future introductions of systemic innovations characterized by network externalities.

The case analyzed, included cooperation of directly involved: government, power company and a supplier of OEM manufacturers. The time period for this study did not include the final ending of the innovation. Hence, it was not possible to conclude whether the introduction was successful.

Preliminary results of the research indicate that the organizations and coordination of the introduction founding a foundation forms an appropriate coordination mechanism. It was concluded that by adjusting the interfaces to the current infrastructure, the effects of network externalities were largely eluded. As well as in order to break through the excess inertia a PPP (public-private partnership) supports the founding of an installed base.

It is recommended that future research focuses on industries other than the automotive. It is also recommended that governmental cooperation on national and international level could be involved.

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Abstract

In this study, the introduction of a systemic innovation characterized by network externalities is examined. Conducting an in-depth case study supplemented with a theoretical study it is observed that organizations, founding an independent entity with an independent board of directors, improve the organization and coordination in introducing an innovation. Additionally the research shows that a PPP proves an effective mean in order to break through the excess inertia caused by the influence of network externalities. These findings provide theoretical and managerial implications in the field of systemic innovation.

1. Introduction: introducing a systemic innovation characterized by network externalities

Today his market economy is characterized by a continuously changing environment. Product development and technologies are rapidly following each other and end-users are ever more demanding. Organizations need to cope with the dynamics within their environment. Not only by improving their existing products or technologies, also by developing new ones[1]. Keeping up with the technological innovative pace, means survival for numerous organizations, being innovative is their flow of life.

Organizations need to innovate in order to sustain or create a competitive advantage and maintain a right of existence. This can be done through small steps on an existing basis or big steps in unknown places.

Several projects focusing on innovation sustainable transport designs have emerged, for instance the hybrid car. This is one of the small number of systemic innovation that do actually make it of the drawing board into production. The studies building the theoretical foundation of systemic innovation and or- network externalities have focused in their theoretical and practical insights on high tech information technologies, i.e. introduction of the mobile phone or the DVD.[2] The most practical insights of how a systemic innovation can be introduced and exploited in the automotive industry, lacks a diverse source of scientific work. Therefore this research focuses specifically on the automotive industry, using the 'Whisper bus', a classic example of successful public-private cooperation.

The current literature does not provide a clear strategy to introduce a systemic innovation characterized by network externalities. The goal of this research is to fill this scientific gap.

[1] MacCormack et al. (2001).

[2] Brusoni and Prencipe (2001).

1.1 Research approach: case study on the introduction of a systemic innovation

The research consists out of 6 steps, starting with the problem definition and methodology. The second step embraces the development of the theoretical framework. By the third step the theoretical model derived from the literature study is displayed and commented. The fourth step encompasses the case study held with the participating organizations in the Whisper project. The fifth step presents the results of the case study. The results of the case study are tested in an empirical model leading to conclusions forming the sixth step. The drawn conclusions provide the data to answer the research question. These steps are visualized in Figure 1.

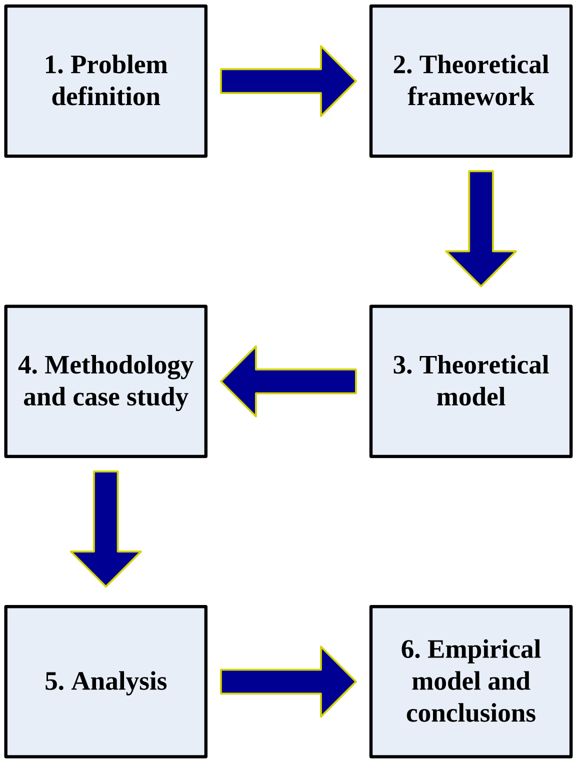

Fig. 1: Steps visualizing research approach

The aim of this study is to provide more insight in the introduction of systemic innovations in markets marked by network externalities. The central question is formulated as follows:

How can a systemic innovation be introduced and exploited in a market characterized by network externalities?

The research question addresses the knowledge that is necessary to reach the research objective.[3] Depending on the premises underlying the research question and the nature of the research, the research question provides new insights. The central research question is an exploratory question, focusing on what is happening, seeking new insights and to assess phenomena in a new light. Hereby seeking which factors influence the introduction of a systemic innovation, marked by network externalities. The following research questions are used to finally answer the main question:

- What is the best strategy for the introduction of a systemic innovation?
- How can the influence of network externalities best be taken into account in the strategy of introducing a systemic innovation?

[3] Verschuren (1999), p. 57-67.

- What are the essential characteristics of the case relating it to a introduced and exploited innovation in a governmental influenced market?
- What determines The Whisper, using the Function Component Allocation scheme, as a systemic innovation characterized by network externalities?

In accomplishing the research objective and answer the research questions, a case study is performed on a introduced systemic innovation characterized by network externalities. This research differs from previous research on systemic innovation due to the innovation its network externality characterization.

Due to the inductive nature of this research a review on former literature is performed which focussed on innovation in general and more specific systemic innovation. Next to systemic innovation the literature research focussed on network externalities and the possible relation and influence of network externalities on introducing innovations.

1.2 Case introduction: The 'Whisper bus' a introduced systemic innovation

Innovations are characterized by the plurality of tempo changes. It is running or get overtaken, but in mind the perspective that sustained progress is made. This also applies to the Whisper, a technological renewal, in innovation argot a 'step change'. Innovation means discovering, not only in technological sense, but also in the way in cooperation and coordination with other parties involved. For that reason the Whisper is remarkable, it is an example of a successful public-private cooperation, where the governance, trade and industry cooperate.

Fig. 2:The Whisper
Source: http://www.theWhisper.nl, (2010)

The invention which makes the Whisper special is a complex and innovative product called The Wheel. At the moment innovation in electrical transport is at the order of the day. After a development phase of several years has been put into practice. It is implemented in the demanding public transportation market.

The following three aspects make the Whisper special[4]:

1) The technical exceptionality of the findings applied in the Whisper;
2) The contribution they deliver against the CO2 emission problems;
3) The cooperation which has led to the definitive introduction in the public transportation of the municipality Apeldoorn.

The Whisper will provide an expected fuel save of 50%, an emission reduction of 50% and a noise reduction of 90%, compared to standard buses using established technologies. And a reduction in maintenance of 80%, due to the fact that the Whisper has les parts that can wear out. The sum of all these advantages makes the Whisper not a representation of an evolution, but a revolution[5].

[4] For the patent of The Wheel see appendix: Patent The Wheel.
[5] For the certification of fuel consumption by TNO appendix: Certification fuel consumption by TNO.

2. Research methodology: deriving a strategy for the introduction of a systemic innovation in a market marked by network externalities

As discussed so far, the purpose of this research is to derive a strategy for introducing a systemic innovation influenced by network externalities. In order to do so, a case study is conducted. This chapter clarifies the reason for performing a case study how this research is applied to be able to answer the main research questions.

2.1 Research design: testing of a theoretical model

The starting point of this study involves: "testing of a theoretical proposition by employing of a research strategy specifically designed for the purpose of its testing." Therefore it is a deductive theory. But the research is also inductive for the model created through deduction, is "revised using data collected from qualitative research", meaning inductive research. Therefore the research is twofold.[6]

The research objective provides insight in introducing a systemic innovative product in a market marked by network externalities. The starting point of this study is a literature research followed by testing the cases product architecture applying a theoretical model. Critical incidents leading to factors that are crucial are found by interviewing stakeholders. Using these data the analytical model is tested. For that reason, the approach of this study is exploratory.

The aim of this paper is to test a theoretical model for empirical work, in the introduction of a systemic innovation, in markets characterized by network externalities. Prior studies in the field of systemic innovation and network externality product introduction have focused more on the coordination, competition and further expansion of products focused on network externalities. As well as the automotive market has not been researched, together with public private partnership .

2.2 Transcribed interviews applicable for qualitative data analysis

In the case study the data were collected by interviewing. Interviews are reckoned to be essential sources of case study information:[7] interviews can provide access to in-depth insights and take place in the natural environment. The use of examples during the interviews

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[6] Saunders et al., (2009) p. 127.

[7] Yin, (1984).

are limited as much as possible, in order not to influence the interviewee. Instead, the interviewer will try to rephrase the question. This approach is chosen to let interviewees provide data as clear as possible and not influence their point of view.

The goal of the interviews held is to gather information from the announcements of questioned persons in order to answer one or more research questions are formulated in advance[8]. Conformable the theoretical framework and the research questions are the foundation for the interview protocol[9]. The opportunity of open questioning and interrogating on answers are other interview features. The interviewer takes an objective and impartial position in order to ensure that the questions are not aiming in a certain direction[10]. In the interview protocol the majority of the questions in the interview protocol are open questions. Open questions are labour-intensive, but for the interviewee it is a stimulation to talk freely[11]. Especially when there is little known about the expected answers, open questions are appropriate.

The conducting of the interviews took place face-to-face. With the advantage that each interviewee is interviewed in their natural environment, leading to enhanced communication. Information is gathered about matters or persons outside the interviewees, therefore the interviewees in this research can be described as informants[12]. Both internal and external informants/project participants are interviewed in order to obtain more valuable data. If possible in different function levels participants were interviewed in order to obtain possible differences in insights among function levels. This is applied within the municipality of Apeldoorn and e-Traction. The length of interviews differed, some participants scheduled an hour, others were not time-bound.

[8] Emans (2002).

[9] Appendix: interview protocol.

[10] Emans (2002).

[11] Yin (1984).

[12] Verschuren and Doorewaard (2005).

To assure effective data collection, recordings are used to provide the most accurate rendition of the interview.[13] During the transcription seven guidelines[14] apply, the three most important are:

1. "Preserve the morphologic naturalness of transcription. Keep word forms, the form of commentaries, and the use of punctuation as close as possible to speech presentation and consistent with what is typically acceptable in written text."
2. "The transcript should be an exact reproduction. Generate a verbatim account. Do no prematurely reduce text."
3. "The transcription rules should be complete. Transcribers should require only these rules to prepare transcripts. Everyday language competence rather than specific knowledge (e.g. linguistic theories) should be required."

In accordance to the guidelines all the interviews were digitally recorded and entirely transcribed by the interviewer in same standardized manner. To ensure confidentiality all transcripts were only accessible for the researcher. Each digital recording is saved, in order to enable the possibility of listening back in case of unclearness. The informants all gave permission for the use of the data, one of the respondents asked for a confidential treatment of his statements.

2.3 Data analysis: defining between a modular architecture and an integral architecture

From the data gathered from the transcribed interviews and additional literature the Design Structure Matrix (DSM) model is applied to reveal the innovation its systemic character. The model is designed around the Design Structure Matrix (DSM), developed by Pimmler and Eppinger[15] and expanded by Fixson[16]. The technique of DSM is originally developed for better understating system engineering needs which arise due to complex interactions between components.

In order to develop a product architecture description that is comprehensive and meanwhile operational, defined as: "A modular architecture includes a one-to-one mapping from functional elements to physical components of the product, and specifies de-coupled

[13] McLellan, (2003), p.64.
[14] McLellan, (2003), p.65.
[15] Pimmler and Eppinger, (1994).
[16] Fixson, (2005; 2008).

interfaces between components. An integral architecture includes a complex (non one-to-one) mapping from function elements to physical components and/or coupled interfaces between components"[17]. The information obtained from this design is used to define the product architecture. Roughly the method consists out of three steps: 1) Decomposing the system into elements: describe the product concept in terms of functional and/or physical elements achieving the products functions. 2) Document the interaction between the elements: identifying the interactions which may occur between functional and physical elements. 3) Cluster elements into chunks: The elements are clustered into chunks based on criteria set by the overall product design strategy. These chunks define the product architecture[18].

[17] Ulrich (1995), p.422.

[18] Pimmler and Eppinger (1994).

3. Theoretical background: outlining the concept of innovation and network externalities

The theoretical framework presented, will start elaborating on the different types of innovation recognized in the literature. Subsequently focusing on the main terms in this research; systemic innovation and network externalities and the factors which characterize them.

3.1 Innovation: development, improvement, adoption and commercialization of a new process or product

As already mentioned in the problem definition, today´s market economy is characterized by a continuous changing environment, and organizations need to innovate in order to sustain some form of competitive advantage. In the field of innovation a lot of different definitions are used to label the type of innovation discussed. In order to define types of innovations, a clear definition of innovation is inevitable.

Starting with the distinction between an innovation and an invention. An innovation is a discovery of serve nature, that goes no further than the laboratory, is an invention. If the discovery moves further into the process and adds economic value, whether it is positive or negative, is marked an innovation. So, when this idea is developed and eventually taken into production, whether it becomes successful or not, an innovation is at hand. The discovery or idea generation can be initiated in almost every layer of the organization and by any employee, whether top-management or blue collar employee. A clear definition of innovation is:[19] “innovation is an iterative process initiated by the perception of a new market and/or new service opportunity for a technology-based invention which leads to development, production and marketing tasks striving for the commercial success of the invention”. A comprehensive review of the innovation literature is provided by Jordan and Teece:[20] “Innovation is the search for, and the discovery, development, improvement, adoption and commercialization of new processes, new products, and new organizational structures and procedures.” The scholars further note that “It is an activity in which “dry holes” and “blind alleys” are the rule, not the exception.”[21]

[19] Garcia and Galantone (2002), p. 112.

[20] Jordan and Teece (1990), p.75.

[21] Jorde and Teece (1990), p.76.

As defined an innovation is not just a product or task on its own, but a process. This process can have very different initiations and outcomes, depending on the innovation type and how the innovation is examined. An innovation can be experienced as just a minor change on an existing product or service by a manufacturer, but completely new by an end-user. The difference is made by the state of the knowledge of the actor who is perceiving the innovation.

The literature[22] distinguishes four different focuses of innovation describing pathways that an innovator can use in his search for good ideas. The first focus of innovation is the improvement or development of products or services *(product innovation),* for instance a new mobile phone. The second focus is the improvement of partly or the whole process of an organization *(process innovation),*for example the use of Lean Management. The third focus is the repositioning of a product or service to create new markets *(positioning innovation),* the Swiss watch industry struggled in the transition from mechanical to digital watches but eventually the industry re-vitalized by the positioning of the watch as a luxury good. The fourth and last change *(paradigm innovation),* for example the global change towards durable energy.

By making the distinction between innovation and invention and defining innovation and recognizing innovation not only as a product but as a process being able to further characterize and define innovation towards systemic innovation. The next step is making the distinction of discontinuous innovation in radical and disruptive innovation.

3.1.1 Discontinuous innovation: distinguishing radical and disruptive innovation

One of the first scholars to use the disruptive innovation concept is Christensen[23] differentiating between sustaining and disruptive innovation- based on technological performance and market segmentations. Technologies that help companies to sustain their growth in the existing or established market place in order to ensure market growth and domination focusing on improvement on the performance of current products and services is referred to as sustaining innovation. These improvements are incremental or radical. "Disruptive innovation" occurs when this new product, entering the market at a lower level of sophistication, rapidly progresses to meet the needs of the majority of consumers in the marketplace and, as a result, captures market share from well established firms."[24] Established

[22] Tidd, Bessant and Pavitt (1999).

[23] Christensen (1997)

[24] Bower & Christensen (1996), p.45.

firms serving the more attractive segments ignore a disruptive technology, because it only serves a small low-marging market.[25] ‘‘Disruptive technologies are typically simpler, cheaper, and more reliable and convenient than established technologies.’’[26] A disruptive technology is distinctively introduced in a new market with lower demands or at the low-end-side of an existing market.

Radical innovations which change core technical concepts and their linkages lead to adaptive challenges for organizations.[27] The radical innovation concept differentiates between incremental and radical innovation through a clear delineation of the technological features that are commercialized, either in new- or existing markets.[28] A radical innovation contains at least one of the following characteristics:[29]

- To create improvements in known performance features;
- To create an entirely new set of performance features;
- To significantly reduce costs.

These characteristics promote radical innovation as a means of gaining and sustaining competitive advantages for established firms to create growth potential. Radical innovations aim at a high-end market, containing users that search for superior performance features and not the cheapest solution. Therefore judging the innovations performance over price.

Examining the potentials[30], the first should be interpreted as based on the current performance features of a product or process, where a huge step can be taken when the radical innovation is applied. The second potential should be interpreted as a set of performance features that have an entirely new potential to outrun the existing products or processes. The third and last potential makes it possible to significantly reduce costs but not affecting the performance characteristics.

Disruptive and radical innovations have a strong resemblance with the difference that lies in the change of performance characteristics. A radical innovation reduces costs without affecting the current performance features, whereas disruptive innovation changes both. The

[25] Christensen (2000).
[26] Christensen (2000), p. 192.
[27] Tushman and Anderson (1986).
[28] Leifer (2000).
[29] Leifer (2000), p.5.
[30] Leiffer (2000).

core principle of a disruptive innovation is that it satisfies demands for a product with a low price and performance features which do not need to be the same as of existing products. A conceptualization of the major difference in the perception of the end-user, the market. "Radical innovations typically enter the marketplace at the higher-end where performance is more important than cost. Subsequently, with sustaining innovations, they could rapidly reduce cost and capture the mass markets. Disruptive innovations, on the other hand, are typically targeted at the low-end customers, or new markets where the need is not satisfied in the past (competition against "non-consumption") and hence any product which could "do the job" and yet affordable could sell."[31]

"A disruptive innovation is applicable on the low-end side of an existing market or a new market which has much lower demands on performance and different price perceptions. A radical innovation is typically applicable on high-end side of an existing market or a new market with higher demands on performance."

3.1.2 Deducting architectural innovation to systemic innovation

The research field is categorized into four main definitions[32]: Incremental Modular, Radical and Architectural innovations.

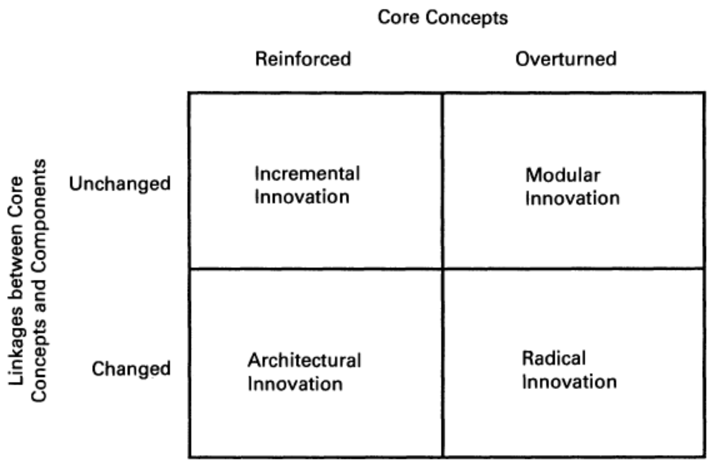

Fig. 3: Framework for defining innovation
Source: Henderson and Clark (1990), p. 12

Architectural innovations change the linkages between components of a product but leave the core design concepts intact. A different view focuses on different performance characteristics and addressing new customer groups.[33] There are some difficulties for firms adapting to architectural innovation. Architectural innovation present firms a more subtle change than radical innovations do. Much of the firms knowledge is useful and applicable in the new product, but some of the knowledge is not only useful but could in fact handicap the firm. Recognizing what is useful thereby acquiring and applying the new knowledge if necessary, can be quite difficult for an

[31] Hang, Neo & Chai (2006), p.255.

[32] Henderson and Clark (1990).

[33] Christensen and Bower (1996).

established firm on account of the way knowledge and especially architectural knowledge, is organized and managed.

Different authors have defined architectural innovation in different ways. "Architectural innovation is often triggered by a change in a component-perhaps size or some other subsidiary parameter of its design-that creates new interactions and new linkages with other components in the established product".[34] A similar definition focuses on changes in (at least) one component which requires substantial modification in components throughout the system (most often in terms of physical properties such as volume and area).[35]

Based on the amount of integrative efforts, or the coupling of activities, that is required in a development is a stronger related to product complexity than technological change.[36] A distinction can be made between the characterization of the development process in systemic and analysable complexities. "Systemic complexities refers to situations when the development task comprises severe and unforeseeable technical interdependencies, something that makes separation and specialisation difficult."[37] The last to be added to the innovations list is systemic innovation, meaning: innovations requiring considerable adjustments in other parts of the business system they are integrated in.[38]

3.2 Introducing systemic innovations: commercializing the new process, product and new organizational structures and procedures

There is a distinction in the characterization of the development process between analysable and systemic complexities. Systemic innovation is a specific type of technological change, operating through a specific mechanism and has specific consequences.

The amount of integrative efforts, or the coupling of activities- required in a development, is stronger related to product complexity than technological change.[39] Dividing the characterization of the development process in systemic and analysable complexities: "Systemic complexities refers to situations when the development task comprises severe and unforeseeable technical interdependencies, something that makes separation and

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[34] Henderson and Clark (1990) , p.12.

[35] Langlois (1988).

[36] Lindkvist et al. (1998).

[37] Magnusson et al. (2003), p. 7.

[38] See Teece (1986), Chesbrough and Teece (1996) as well as Brusoni and Prencipe (2001).

[39] Lindkvist et al., (1998).

specialisation difficult."[40] A different characterization views a systemic innovations a as an innovation that requires interrelated changes in product design, supplier management, information technology.[41] In this paper the following definition applies: innovations that require significant adjustments in other parts of the business system they are embedded in.[42]

3.2.1 How it works: network externalities as key to the economics of systemic innovation

A number of product-related dimensions have been linked to NPD outcomes are expected to have a diverse effect on performance, which is dependable on the degree of innovativeness of the product.[43] Demonstrated product superiority is an example of these product-related dimensions. For discontinuous innovations, a clear example of incorporating a new technology to handle customer/environmental concerns in a more effective way, in providing a significant comparative advantage in order to secure adoption by customers. A pitfall in which companies can step is the overenthusiastic focus on technological advances resulting in the development of refined, though costly, solutions to relatively simple, non-existent or non-core problems. The focus on product superiority is more important than in continuous innovation since producers face a lower purchase risk when applying/purchasing a continuous innovation.

Although much has been written about systemic innovation, there has been little focus on the introduction of systemic innovation in products marked by network externalities in the automotive industry. The force of network externalities shows that interdependent demand can sustain continual growth in a static population with a static income.[44] The mechanism works as follows. "New subscribers join. This increases the incremental utility of the service and induces marginal nonusers to join. That in turn induces further growth etc., etc."[45]

New network externality products often face coordination problems because the installed base and the complementary goods that add product value are not available yet.[46] The installed base can also be defined as "an "equilibrium user set", a set of users consistent with all individuals (consisting out of users and nonusers) maximizing their utilities."[47] An installed

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[40] Magnusson et al., (2002), p.7.
[41] Chesbrough and Teece, (1996).
[42] See Teece (1986); Chesbrough and Teece (1996); as well as De Laat (1999).
[43] Brentani (2001).
[44] Rohlfs (1974).
[45] Rohlfs, (1974), p. 18.
[46] Dew and Read (2007).
[47] Rohlfs (1974), p. 16.

base, and network externalities arises when buyers wish to "communicate" directly with each other. Network externalities also arise when the presence of a large installed base allows manufacturers (of complementary goods) to exploit economies of scale.[48] The absence of these factors makes it hard to break through this vicious cycle. An investment in the installing base is necessary to break through the cycle and enhance customer network externality adoption.[49] "It is commonly believed that the presence of these installed-base effects, known as network externalities, makes it excessively difficult for firms to enter the market with new products or new technologies; lacking an installed base of past buyers, a firm with a new technology would be unable to convince consumers to join its fledgling network –even if the new product were clearly superior to existing ones."[50] Markets where there is a bias towards the existing systems over newer systems, superior to the existing lacking an installed base of users, is defined as excess inertia. "The introduction of a new product in a market with network externalities. There is a common presumption that such markets exhibit excess inertia, i.e. that they are biased towards existing products."[51] Figure 4 presents the insight in the investment needed to break through this cycle. This figure shows how to overcome the impasse of the status quo between the installed base and the product value.

As figure 4 shows the market consists out of an installed base and a product value who are enforcing each other. When the coordination is achieved, the market will expound, due to products becoming more valuable owing a larger installed base and the availability of complementary goods.[52]

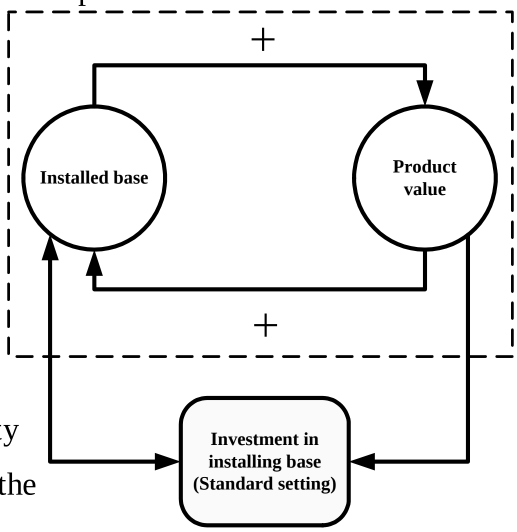

Fig. 4: Creating a breakthrough in the installed base Based on: Dew and Read. (2007)

The adoption of an Industry Standard, the compatibility mechanism is the adoption of an industry standard; the firms must jointly decide to make their networks compatible. In some circumstance the producers of alternative technologies have strong incentives to design their products to be standardized or construct an adapter to be compatible.[53]

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[48] Katz and Shapiro (1992).

[49] See Gandal et al. (1999); Srinivasan et al. (2004); as well as Brynjolfsson and Kemerer (1996).

[50] Katz and Shapiro (1992), p. 56.

[51] Katz and Shapiro (1992), p.55.

[52] Dew and Read (2007); Katz and Shapiro (1985).

[53] See Gilbert (1992); Katz and Shapiro (1992); as well as Forell and Solaner (1986).

Recapitulating, new network externality products often face coordination problems due to the lack of an installed base or an equilibrium user set. Breaking through this so-called excess inertia is possible when a subsequent investment in the installed base has been made or when producers of alternative products make their products compatible to the new product.

3.3 Systemic innovation: innovations that influence the product architecture of the business system they are integrated in

It is clear that the concept of innovation is an idiosyncratic definition. "An iterative process initiated by the perception of a new market and/or new service opportunity for a technology-based invention which leads to development, production and marketing tasks striving for the commercial success of the invention."[54]

The concept of innovation is further deducted into systemic innovation. Systemic innovation is characterized by changes which are not known on forehand, in one or more components, requiring substantial modification in components throughout the system.[55] Based on foregoing definitions in this paper defines systemic innovation as: "innovations that require significant adjustments in other parts of the business system they are embedded in."[56]

The systemic nature of innovation, combined with the uncertainty that it brings, makes it a challenge for organizations to manage the process as correct as possible. Systemic innovation being dominant in the development of complex products, and parts of complex products, with products consisting out of many interrelated components and subsystems. Resulting in components which scarcely can be changed without requiring changes to other parts of the product. In this systemic context it is an organizational challenge for innovating organizations to develop and renew product systems. The organizational and managerial capability to deal with these issues of systemic innovation in the literature referred to as systems integration.

The new product architecture is developed in a way that existing product systems can be attached in the light of component innovation, or modular innovations. The remark/approach 'firms more than they make' stimulates firms to monitor and absorb these external technological developments.[57] Integrating this external knowledge provides organizations

[54] See Farell and Solaner (1986); Gilbert (1992); as well as Katz and Shapiro (1992).

[55] Langlois (1988).

[56] Markku et al. (2005), p.3.

[57] Brusoni and Prencipe (2001).

with detailed architectural knowledge on component or modular interrelationships. This knowledge is the heart of their systems integration capability.[58]

Systems integrators need to monitor modular component innovations, which are based on existing interfaces, in order to learn about possible imbalances and what technological changes are required to other components.[59] Whereas architectural cannot readily be implemented in the product system due to required interface changes.[60] Consequently, a system integrator needs to identify interdepencies and coordinate specifications of new interfaces. The intensive exchange of coordinative information is needed in designing new interface specifications.[61]

Therefore there should be close links with, for instance, specialized suppliers as well as the monitoring of technological innovations in other industries. This refers to the importance of vertical and horizontal linkages.

[58] Van den Ende et al. (2008).

[59] Van den Ende et al. (2008).

[60] Van den Ende et al. (2008).

[61] Van den Ende et al. (2008).

4. Organizing systemic innovation: Consequently, system integrator need to identify interdepencies and coordinate specifications of new interfaces

In organizing a systemic innovation there are several core issues forming the pillars. The first area focuses on describing the characteristics of a systemic innovation. The second focus area is the structure and linkages that organizations have and need to use for organizing the innovative process. The final pillar consists out of the coordination of activities and how to deal with coordination problems.

4.1 Structure: centralized or decentralized structuring of the innovative process

Paragraph 4.1 focuses on structuring the firm organization when managing the innovation process. In structuring these innovations there are two major distinctions the centralized and decentralized organization, and horizontal and vertical linkages.

4.1.1 The order of control centralized or decentralized organization

Systemic innovation projects have to generate the architectural knowledge on how technology suppliers and other parties can be best interconnected. Because different components have never been combined before, this makes it difficult to specify and develop the component interfaces. Upfront little is known about how components will interact and how they can be adapted in order to create a consistent system.[62]

The academic literature structures the firm organization of innovating in a systemic way in centralized and the decentralized organization. Several scholars argue that the only firms that can innovate in a systemic way are strong and integrated, following the internal organization.[63] Coalitions consisting of joint ventures, alliances or virtual partners will not be able to create a systemic innovation nor be able to set standards or control further evolution. Integration of all necessary activities into the corporation is the only organizational solution that will make the grade when introducing and exploiting a systemic innovation.[64] Network alliances are regarded only useful when it concerns an autonomous innovation. Main argument for holding on to the single firm position is the order of control. The integrated firm

[62] Jaspers (2009).

[63] Teece (1996).

[64] Chesbrough and Teece (1996).

is to be considered as the strongest form of control.[65] The virtual company, holding together a bundle of outsourced activities is supporting the internal organization, which is perceived to enclose the least amount of control.[66]

Decentralized organization of innovating in a systemic way is derived from the internal organization. It differs to internal organization, unless there is a leading firm in the network, perceived as to be almost as strong as an integrated corporation.[67] Recapitulating the view of the single-integrated corporation form it argues that alliances are not appropriate arrangements to innovate in a systemic fashion. Because it is not capable to innovate in a systemic fashion, nor to set systemic standards or further develop a new technological regime.[68] The centralized organization lies between the internal organization and decentralized organization. The common forms such as strategic alliances and joint ventures, may almost rate as strong control when there is a leading firm.[69] The strongest critics enclose that companies may be reluctant to make the necessary transaction-specific investments out of fear that advantage is taken of it and tacit knowledge sharing is obstructed.[70]

Opposed to the internal organized systemic innovation scholars argue that industrial structure is changing from vertical to horizontal and digital convergence is taking place. In this light systemic innovation can only be undertaken by alliance networks. Although these networks are vulnerable to opportunism, relations can be established through both substantial and procedural commitment. Industry standards can be set by expanding the alliance network.[71] Companies seem to undergo a transition from a vertical to a horizontal structure. Faced with new competitors, companies are forced to move into broader terrain, due to the risk of being outcompeted. The necessity of keeping up to date with the technological developments, alliances across industrial boundaries becomes more common.[72] This trend seems to enhance the decentralized cooperation and cooperation through horizontal linkages.

Recapitulated the academic literature regards two main organizational structures, the centralized and the decentralized organization. The centralized organization consisting out of

[65] De Laat (1999).

[66] Chesbrough and Teece (1996).

[67] Chesbrough, Teece (1996).

[68] See Teece (1984); Teece (1986); as well as Teece (1996).

[69] De Laat (1999).

[70] De Laat (1999).

[71] Yoffie, (1997); De Laat (1999).

[72] Yoffie (1997).

a singular organization and the decentralized organizational structure. The accessing of new or alternative competences and knowledge bases in the market, thereby mitigating the risk of technological obsolescence empowers the decentralized organizational structure.

4.1.2 Horizontal and vertical linkages in the complete network: coordinating suppliers and customers

Horizontal and vertical linkages are inevitable when coping with a systemic innovation. Especially in the level of interdependence between the supplier organizations and the setting in which the innovation needs to be implemented. Systemic innovation projects have to generate the linkages between the components and subsystems, hence they cannot use the path followed by existing products.

The vertical structure and associated links to external suppliers can have a direct influence on its innovative activities.[73] There are different views regarding the effects of technological uncertainty on firms' integration decisions, whether uncertainty leads to integration or disintegration at firm level.[74]

In the cooperation using vertical linkages the focus lies on Transaction Costs (TCE). The major sources of transaction costs in the literature are: uncertainty, frequency of contract updates, asset specificity physical, human, site and dedicated assets.[75] Higher uncertainty leading to higher transaction costs. Hence, firms will organize their boundaries to minimize these costs. Vertical integration prevents unnecessary bargaining and uses authority to harmonize interests, risk perception, expectations and resource allocation.[76] Therefore, higher uncertainty will lead to higher degrees of vertical integration in an industry. Internal organization moderates these problems cope with uncertainty by using gradually adjusting decisions.[77]

Next to the TCE, there is the Knowledge Based View (KBV) which explicitly argues that the reason of existence for organizations is the efficient transfer and creation of information and know-how. KBV involves higher-order routines, knowledge, skills and learning and are the result of organizational components following each other.[78] According to the KBV, firms in

[73] Teece (1996).
[74] Walker and Weber (1987); Schilling and Steensma (2002); as well as Hoetker (2005).
[75] Williamson (1983).
[76] Wolter and Veloso (2007).
[77] Langlois (1988).
[78] Langlois (1988); Madhok (2002).

an innovative environment which is characterized by technological uncertainty internalize activities not because of disadvantages (transaction costs), but because of the benefits of coordinating preceded by and within the same organization complementary- and similar activities.[79]

These advantages are created because organizations develop routines and language tools through training. These routines become efficient in transferring knowledge and tackling tasks that require quick adaption .[80] The presence of technological uncertainty might lead to parties (unintentionally) keeping knowledge private, being related to the presence of high degrees of tacit knowledge. Because tacit knowledge can more easily be transferred within an organization, vertical integration would be the outcome to prevent the leakage of knowledge.[81]

When customers are underserved by a technology with an uncertain future, firms are constantly trying to evolve the products with interdependent designs.[82] Arguing that this interdependency, which comes down to interfaces within the product architecture that are not well specified, leading to changes in design specifications can easily affect additional ones. This involves a lot of tacit knowledge and requires unstructured technical dialog, best performed in a single organization. Organizations with upstream capabilities and high risk of obsolescence have low incentives for vertical disintegration.[83] Where-as systemic innovations where coordination needs and transaction costs as well as the incentives for vertical integration are high.

In general the purpose of horizontal collaboration is to carry out basic research and establish standards.[84] Firms are likely to work with competitors when they share common problems that are outside the area influenced by the competitor.[85] Another incentive aligning with competitors can be pre-competitive research programs.[86] This type of collaboration does not seem to be the most appropriate mechanism in achieving productive innovations.[87] The

[79] Wolter and Veloso (2007).

[80] Langlois (1988); Hoetker (2005).

[81] Christensen, Verlinden and Westerman (2002); Teece (1982).

[82] Christensen, Verlinden and Westerman (2002).

[83] Wolters and Veloso (2007).

[84] Tether (2002); Bayona et al. (2003).

[85] Tether (2002).

[86] Nieto et al. (2007).

[87] Bayona et al. (2003).

problems of information leakage and the risk of hold up are greater when working with competitors. Which can be decisive in the a firm his cost-benefit analysis against collaborating with competitors when the firms objective is to achieve product innovations, even more when concerning innovations with a high degree of novelty.[88] In their research using data from a longitudinal sample of Spanish manufacturing firms the conclusion is drawn that collaborating with competitors turns out to be the least fruitful way of producing novel innovations.[89] This conclusion is consistent with earlier studies which highlights performing basic research and establishing standards as reasons for collaborating with competitors.[90] More recent research performed supports the statement that collaborating with competitors has a negative effect on innovation, found that collaboration with competitors are associated with lower product innovation in the firm.[91] Who are reluctant to share knowledge due to the threat of unexpected transfer of knowledge and therefore become more careful regarding the knowledge shared.[92]

Opportunistic behaviour is usually less within hierarchies, because transactions tend to take place in formalized ways.[93] Hierarchies will not eliminate all opportunistic behaviour, because organizational politics or abdicating on jobs hinder coordination. An equity alliance would be able to counter these negative effects. “Some characteristics that equity alliances share with hierarchies appear to deter opportunistic behaviour: aligned interests, monolithic control, and diminished performance ambiguity.”[94]

4.2 Process: sequencing target directed activities

The process comprises out of the coordination of activities. The coordinated activities can result in coordination problems regarding network externalities. How to cope with these autonomous and systemic coordination problems be answered. As well as incentives and governance. And finally deriving a framework for analysis using the Function Component Allocation scheme (FCA).

[88] Nieto et al. (2007).
[89] Nieto et al. (2007).
[90] Tether (2002); Bayona et al. (2003).
[91] Annique Un et al. (2010).
[92] Annique Un et al. (2010); Hamel (1991).
[93] Gulati (1995).
[94] Kale and Singh (2009), p. 48.

4.2.1 Coordination of activities: synchronizing of interdependencies by sharing information and adjusting throughout the entire product system

Systemic innovation projects have to generate the architectural knowledge on how technology suppliers and other parties can be best interconnected. Contradictory development projects or autonomous innovations can benefit from the existing capabilities. The different components have never been combined before, this makes it difficult to specify and develop the component interfaces. Upfront little is known about how components will interact and how they can be adapted in order to create a consistent system.

By their very nature, systemic innovations require information sharing and coordinated adjustment throughout an entire product system.[95] In the "old model", closed innovation, where coordination often only takes place with supplies and customers. In the open innovation model, with systemic innovation processes firms need to coordinate both vertically with producers (of complementary products) as horizontal with direct competitors to ensure that the innovation is viable.

Coordination integration referred to as the extent of information exchange between two stages of production to achieve so-called 'unity of effort'.[96] In this context it is defined as the extent of information exchange between the system firm and the implementing firm to make sure that the component fits into the whole system. A high degree of coordination, integration is needed if the component is highly interdependent with other components in the product.[97] In this situation of systemic innovation, intense information-processing is needed, for instance by mutual adjustment and coordination between the teams.[98] This coordination can be lower or performed without any information-processing, referred to as low coordination integration, when the new component operates in an environment of existing interfaces.[99] Though related, it is important to make a distinction between coordination integration and ownership integration.[100] Further identifying that information processing occurs within the system firm when it involves an internal project, but when information processing takes place across firm boundaries when external projects have to be coordinated. The extent of processing

[95] See Chesbrough and Teece (2002); Langlois and Robertson (1991); as well as Maula et al. (2005).

[96] Lawrence and Lorsch (1967).

[97] Brusoni et al. (2001).

[98] Chesbrough and Teece (1996); Dew and Read (2007).

[99] Brusoni et al. (2001).

[100] Robertson and Langlois (1995).

information between the system firm and the component development project, reflects the strength of the tie between the two organizations.

Without tight 'coordination integration' interdepencies might not be discovered until architectural problems arise in later stages of the development process.[101] Furthermore, internal coordination is vital to effectively coordinate supplier relationships, especially in the start-up phase.[102]

4.2.2 Solutions to coordination problems regarding network externalities

Several tools exist for increasing product value to the consumer and accelerating adoption.[103] The first is price reduction,[104] changing product attributes and waiting for time to pass by. Criticizers[105] argue that price reduction would kick-start the adoption on the short run, but it puts pressure on the profitability for suppliers and form a low price ceiling. The change of product attributes is hard, especially in a network externality setting, because some attributes not only affect suppliers but also producers of complementary goods. Waiting would provide competitors time to market and product obsolescence could enter.[106]

In order to break through the excess inertia the literature provides three main tools: standardization, alliances and leadership. According to the standardization literature setting technology standards accelerates adoption, because standardization reduces the risk of product incompatibility.[107] A huge number of standard-setting organizations exist and also the role of government-sponsorship in some form has accompanied standards.[108] Secondly supply-side alliances are a mechanism for the acceleration of adoption.[109] Cooperation with potential rivals (horizontal cooperation) is also a way of reducing the number of standards on the market. Alliances can also help with introducing complementary goods who build the perception of a critical mass around a product. Leadership, mostly given by those with market power in their industries and lead adopter those which are decisive in which innovation gets adopted are coordinating points. It may seem that leaders are using economical and political

[101] Robertson and Langlois (1995).
[102] Takeishi (2001).
[103] Dew and Read (2007).
[104] Dranove and Gandal (2003).
[105] Dew and Read (2007).
[106] Dew and Read (2007).
[107] Tassey (2000).
[108] Swann (2000).
[109] Tsoutsos and Stamboulis, (2005).

power to enforce the innovation but they can be useful in setting the standard in a market with a scattered set of actors.[110]

4.2.3 Incentives and governance

Complex products consist out of many technologically separate components and subsystems. No single organization can therefore handle all technologies involved and internally develop all of the products components and subsystems.[111] The development of complex products involves significant networks of collaborating component and technology developers.[112] Next to this, complex products are typically highly interdependent and require compatibility among the customized components for the product as a whole to perform as it should.[113] There is a strong need for the coordination and control as it was applied in the closed innovation approach.[114] The need for coordination and control is important due to the rapid technological change and the major investments that are required to fund complex product innovation.

When partnering firms lack understanding of component interactions and non-attendance of a mutual understanding of on another their technologies, makes it difficult for partnering firms to come upon agreement over component trade-offs (i.e. to which party is the patent liaised) and the design of a joint product architecture. This could lead to the occurrence of disputes due to different interests of goals, differences in opinion as a result of varied frames of reference.[115]

The installed base-effect explained in the network externalities paragraph 3.2.1 showed the “chicken-and-egg” problem. A new technology comes available but if users do not adopt the new technology in satisfactory numbers, due to the expenses, the manufacturers cannot take it in those levels of production to make it profitable and lower the costs. The solution to this problem is often recognized by organizations, not able to coordinate the activities to reach a preferred solution.[116] Next to this individual shortcoming, other organizations only want to participate if other organizations participate, afraid that others will profit from their work.

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[110] Foss (2001).

[111] Hobday et al. (2005).

[112] Miller et al. (1995); Brusoni and Prencipe (2001b).

[113] Hobday (1998).

[114] Teece (1986).

[115] Hitt et al. (1997); Li and Hambrick (2005); as well as Gulati et al. (2005).

[116] Dew and Read (2007).

4.2.4. Coping with autonomous and systemic problems

The coordination is important in how to tackle architectural problems that are arising. As within the characteristics of the innovation systemic vs. autonomous, this distinction can also be made between autonomous problems and systemic problems. Autonomous problems are problems related to 'hidden design rules' individual components with no implications for other components.[117]

Opposing, systemic problems are related to multiple components and possibly affect the entire product architecture.[118] This could have enormous implications for the existing product architecture. Leading to not only to revising the design of the exterior of the product but also the resizing and reprogramming of existing components such as software.

In order to solve these systemic problems efficient, development teams can be expected to require not only deep component knowledge, but especially knowledge about the interrelation of components.[119] Systemic problems are likely to require decisions from project management and system engineers to unravel design trade-off as well as extensive coordination between team members to unravel interdepencies.[120] If project problems are predominantly systemic in nature it is expected that project teams are more appropriate to solve problems when they are tightly coupled. When the organization form of the project within the organizations facilitates coordination and integration among the responsible project members who are responsible for different parts of the new product.[121]

4.3 Organizing a systemic innovation: the paradox of equity and non-equity alliances

Helping firms in strengthen their competitive positions alliances are an appropriate coordination mechanism. "A strategic alliance is a purposive relationship between two or more independent firms that involves the exchange, sharing, or co-development of resources or capabilities to achieve mutually relevant benefits".[122] A strategic alliance can span over one or more parts of the value chain and several organizational configurations, for example with an equity based alliance such as a joint venture.

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[117] Baldwin and Clark (1997).

[118] Chesbrough and Teece (1996).

[119] Henderson and Clark (1990).

[120] Teece (1996).

[121] Brusoni et al. (2001).

[122] Gulati (1995).

Alliances help firms strengthen their competitive position by enhancing market power[123], increasing efficiencies,[124] accessing new or critical resources or capabilities[125], and entering new markets.[126]

The success of any single alliance depends on some key factors that are relevant at each stage of alliance evolution.[127] These key factors include: a) the formation phase, wherein a firm deciding to initiate an alliance, selects an appropriate partner b) the design phase, wherein a firm (and its partner) set up appropriate governance to oversee the alliance, and c) the post-formation phase, where a firm manages the alliance on an ongoing basis to realize value.[128]

"On the other hand, commitment seems particularly critical in alliances where partners have identified the specific benefits they expect to gain by coming together, but remain relatively unclear about the exact processes necessary to achieve them. In these alliance relationships, partner commitment is more important than usual, as partners must be willing to dedicate costly resources to the relationship and pledge to work with each other even when they realize that some adaptation might be required in the future in light of the uncertainty that exists."[129]

The two most important factor during the post-formation phase are managing coordination between partners and developing trust between the partners.[130] Alliance partners must coordinate their actions to manage their interdependence and realize the benefits of their relationship. But severe coordination problems can result from the lack of sufficient knowledge about how ones actions are interdependent with the others, what decision rules a partner is likely to use, how to allocate resources, or how information should be handled.[131]

To manage coordination successfully, alliance partners can use any or all of three classic mechanisms: programming, hierarchy, and feedback.[132] Programming is the least complex of the three mechanisms. It involves developing clear guidelines on what specific tasks need to be carried out by each partner, who exactly is accountable for each task, and a timetable for

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[123] Kogut (1991).

[124] Ahuja (2000).

[125] Rothaermel & Boeker (2008).

[126] Garcia-Canal et al. (2002).

[127] Gulati 1998.

[128] Schreiner, Kale, & Corsten (2009) p. 1402.

[129] Kale and Singh (2009) p. 48.

[130] Kale and Singh, 2009.

[131] Gulati, Lawrence, & Puranam (2005).

[132] Galbraith (1977).

implementing them. This mechanism facilitates coordination by improving the clarity and predictability of partner actions, reducing frustration, and increasing decision- making speed. Use of interfirm knowledge-sharing routines.[133]

The government structures are differentiated into two categories, equity alliance and non-equity alliances.[134] Equity alliances involve the transfer or creation of equity ownership, and they take two primary forms: direct investment and joint ventures. Direct investment occurs when one of the partners acquires partial ownership of the other partner or partners. In joint ventures, partners invest in a new, jointly owned entity.[135] A joint venture is a shared equity enterprise wherein the participants have committed less than all of their resources.[136] "Direct investment occurs when one of the partners acquires partial ownership of the other partner or partners".[137]

"Non-equity alliances, on the other hand, do not involve any equity transfer, so that they include all kinds of contractual arrangements."[138] Non-equity alliances are able to mitigate performance risk, but not relational risk.[139] Thus, when performance risk is perceived as more serious than relational risk, non-equity alliances are selected.[140] Non-equity alliances are more like market-based contracts rather than hierarchies, as a lack of shared ownership makes it difficult to align the interests of the partners, to control their behaviour, and to distribute performance outcomes. Consequently, opportunistic behavior is hard to curb.

Thus, non-equity alliances are much more flexible. There is no transfer of equity, leading to a low level of commitment. Both partners in the alliance can easily end the alliance. Which would not be as easy in an equity alliance.

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[133] Dyer & Singh (1998).
[134] Pisano (1991).
[135] Das et al. (1996), p.828.
[136] Kent (1991).
[137] Das et al. (1996), p.828.
[138] Das et al. (1996), p.828.
[139] Shan (1991).
[140] Shan (1991).

5. Empirical model determining the systemic character: FCA a product architecture assessment

The literature study forms the input for testing an empirical model, demonstrating the relationships between the factors influencing the introduction of the systemic innovation characterized by network externalities.

In order to analyze the many effects that individual product architecture characteristics practices on different decisions across the domains of product, process and organizational interfaces part of the Design Matrix Structure (DSM), the Function Component Allocation (FCA) is applied. Which is extended by looking at the interfaces and their impact on organizations. This, extended by the influence of network externalities is where this paper focuses on. A model consisting out of various criteria to be able to examine whether the innovation is systemic and a solution to cope with the influence of network externalities is presented.

To build on the definition that a characteristic feature of a product architecture is the way in which functions are allocated to components, requires a mechanism to determine this in a reliable way. Meaning that all the three core components of the FCA scheme need a strict procedure to ensure that results are consistent. These three core components, 1) definition of a function, 2) definition of a component 3) the establishment of the allocation scheme.

5.1 Product architecture: the function component allocation scheme

Efforts and collaboration of great number of participants from various backgrounds are required to design and develop complex engineering products. By applying management tools that model the interface and dependencies between decomposed tasks the managerial complexity of the design process is controlled. Four major steps are included in managing the design process[141]:

1) Model the information and dependency structure of the design process;
2) Provide a design plan showing the order of execution for the design tasks;
3) Reduce the risk and magnitude of iteration between design tasks;
4) Explore opportunities in reducing the project cycle time.

[141] Assine et al. (1999).

In managing and controlling projects design process modeling and management tools are developed. In managing and controlling projects, firms commonly use a variety of activity based tools. One of the first are the Gantt charts. “In their initial incarnation Gantt charts were a production planning tool used to plan and manage batch production. In modern terms Gantt used a time-phased dependent demand approach to production planning. Gantt his production planning worked in a ‘‘top–down’’ manner by linking end item requirements to their constituent components with time-phased production to allow all components to be available when needed for subsequent production activity.”[142] Another traditional management tool is formed by the Project Evaluation and Review Technique (PERT) method.[143] In the PERT method, each task is given three probabilistic time estimates. A variation of the PERT method is the Critical Path method (CPM).[144] The CPM differs that it presumes a time-cost tradeoff instead of probabilistic times used in PERT.

The methods resemble in improving the process by outlining the critical activities. “They do not consider iterations and feedback loops that are characteristics of engineering designs, and they ignore the concurrency and overlapping of the design process.”[145] The traditional project management tools (PERT, The Design Structure Matrix (DSM)[146] provides a more compact representation of a design process. “If the system to be represented is a project composed of a set of tasks to be performed, you can use the matrix approach with the Design Structure Matrix (DSM).”[147]

The (FCA) product architecture framework is used as a guideline to focus on design decisions critical for the case. “The FCA helps to indentify the architectural characteristics that best serve the strategy during early product design.”[148] As well as developing a deeper understanding about the ways “in which product architecture choices are linked to many decisions across the domains of product, process and supply chain.”[149]

[142] Wilson (2003), p. 431.
[143] Cleland, D and King W. (1968), p. 307.
[144] Spinner (1989).
[145] Tang et al. (2000), p.480.
[146] Steward (1981).
[147] Yassine (2004), p. 1.
[148] Fixson (2005), p. 346.
[149] Fixson (2005), p. 366.

5.1.1 Product architecture: the function component allocation scheme

Focusing on assembled hardware products the product architecture is “the scheme by which the function of a product is allocated to physical components.”[150] This scheme includes 1) the arrangement of functional elements, 2) the mapping from functional elements to physical components, 3) the specification of the interfaces. A distinction between product architectures is generally made into two original type of product architectures: modular and integral architectures. “A modular architecture includes a one-to-one mapping from functional elements to physical components of the product, and specifies de-coupled interfaces between components. An integral architecture includes a complex (non one-to-one) mapping from functional elements to physical components and/or coupled interfaces between components.”[151]

Most of the real products lie between the boundaries of modular or integral.[152] Most important are the differences between products or between product generations.[153] Addressing modularity scholars have focused on a systems ability to separate a systems components and recombine it without too much loss of its functionality/activity.[154]

The assessment interface is separated into three exclusive sub-characteristics: 1) interface strength, 2) interface irreversibility, 3) and interface standardization. Interface strength focuses on the interfaces technical nature (id est: transfer of mechanical forces, signals and materials). Interface irreversibility measures the effort that is required to disconnect the interface. Interface standardization is a measure describing the degree that surrounding components manufactured, including those from other firms, are compatible with the present component.

“The way in which functions are allocated to components requires a mechanism that determines and measures this dimension reliably.”[155] Meaning that all three segments of the FCA need a solid procedure to make sure that results resume: 1) what is a function, 2) what is a component and 3) how is the allocation scheme established.

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[150] Ulrich (1995), p. 419.
[151] Ullrich (1995), p. 422.
[152] Ulrich (1995); Schilling (2000).
[153] Fixson and Park (2008).
[154] Sanchez and Mahoney (1996); Schiling (2000).
[155] Fixson (2005), p. 352.

5.1.2 Determination of product functions and components

When determining the functions for product architecture assessment two aspects need to be reconsidered. First, what are a products functions and secondly how can they be determined. The definition of a function includes technical functions as well as marketing functions. The attributes are provided on a similar level to provide a coherent comparison.

The framework is used as a tool to compare products focusing on the differences in their product architectures. The results of the function selection lead to a 'level' on which the differentiation in function-component allocation between the products becomes clear. This results in selecting functions that are fully or almost on comparable way performed by the different system architecture. The function selection should neither choose the highest level of the function, nor the lowest, in order to be significant.[156] The function on the highest level is obviously performed, since otherwise there should not be any reason for the existence of these components. On the other hand when the level of the function chosen is too low, only one component participates in this function, resulting in no other components participating in the performance of this function. Then it would be very likely to predestinate its filling in with other parts and components.

Equivalent to product functions, there are two aspects which stimulate the product component determination: 1) what is a component and 2) how is it determined?[157] The definition of a component here used is a placeholder. Reason for defining a component as such is that this way it can represent a wider range of aspects such as: subsystems, parts, modules. The ultimate representation of the component is depending on the products selected hierarchy level. The phenomenon of manifestation in a hierarchy and the existence as a part of a larger system of assembled products, nested hierarchies.[158]

5.1.3 Function Component Allocation schemes (FCA)

In order to increase product variety a products functions or attributes are varied, but almost never all of them. The basic idea of concepts such as product platforms and commonality is to reuse parts of a product across a product family or even product generations.[159] This implies that the extent to which a product is (non-)modular is information required for each individual function and attribute. Important is how exactly a function is different from the perfect

[156] Fixson (2005).

[157] Fixson (2005).

[158] Gulati and Eppinger (1996).

[159] Fixson (2005).

(modular) situation where a one-to-one relationship exists between a function and component. This is important in redesigning the function-component relationship into a parameter.

The FCA scheme can be determined in three steps, using the products functions and components as they are determined in the previous paragraphs. Starting with constructing a matrix with the products functions in the first column and components in the first row, in order to determine which component contributes to which function. In the most basic way if a component contributes to a function is pointed out using a 1 or 0, the binary allocation procedure.[160]

The second step is to calculate two indices for each separate function that show the deviation of each function from the (earlier mentioned) perfect modular situation, representing a one-to-one relationship with a component. The first index represents the number of components that combined provide a function. This index is calculated for each function in the column, (fig. 10). The second index calculates the extent to which the set of components also contributes to other functions.

5.2 Product architecture: determining interface characteristics

Product interface characteristics are often described using terms as 'coupled' or 'dependent'.[161] But the term coupled is not explicit enough to cover the full load of the product. The way products are coupled can be differentiated in different degrees.[162] A coupling assessing a product function can deviate from the same coupling determining whether a user can easily replace the component providing that function. In order to make the dimension interface measurable the information is classified into three categories: 1) nature, the interfaces' role for the product function 2) 'irreversibility', the role for changing, making and unmaking the product 3) standardization, the role regarding substitutes. Each interface characteristic is approached individually.

5.2.1 Nature of interface

The physical effects that occur for the interface to play its intentional role is reflected by the interfaces nature. An interface can reflect both physical effect as a non-contact relation. The intensity of an interface, reflects its strength and desirability affecting its functional role, its

[160] Fixson (2005).

[161] Baldwin and Clark (2000); Schiling (2000).

[162] Fixson (2005).

nature. The methodology[163] helps describing interaction between components. The upper half of the matrix is used in describing the interaction between components. Thereby allowing the usage of the lower half for determining the level of reversibility of interfaces (paragraph 5.2.2. irreversibility).

After the decomposition of the product into components, the interactions between these components are documented and coded in a matrix, fig. 5. Four forms of interactions can be considered: 1) a spatial interaction identifies needs for adjacency or orientation between two elements, 2) an energy interaction identifies needs for energy transfer between two elements, 3) an information interaction identifies needs for information or signal exchange between two elements, and 4) a material interaction identifies needs for materials exchange between two elements.[164] Specifying the intensity of the interaction using a five-point scale from -2 to + 2. Identifying and scoring each interaction for each of the four forms a matrix within each field four number between -2 and + 2. Where the upper left corner contains the number for the spatial type interaction, the lower left corner displays the number for information type interactions, the upper right the number for energy interaction and the lower right corner shows the material-type interaction rating. Fig 10 presents the interface matrices for the two buses. Empty cells are to be seen as being filled with zeros.

5.2.2 Interface type irreversibility

Irreversibility is the second interface characteristic to be analyzed. The tendency of various product changes over the product life, such as upgrades, add-ons, adaptations and substitution – being assumed as one of the major advantages of a modular product architecture – are strongly dependent on an interfaces' reversibility. Consisting out of the effort that is needed to reverse or disconnect the interface serves as an authority to determine the (ir)reversibility of an interface. This consists out of two factors: the difficulty to physically disconnect the interface and how deep the interface is hidden in the overall products architecture.

In theory every interface can be disconnected. Modular product architectures have strong interactions within the different modules but weak interaction between the modules, this implies that the weakness of these relations can be translated into low efforts in reversing or disconnecting the interface. Next to the way it is connected, it is important how deep the component is 'buried' in the product. When a lot of parts first have to be removed in order to

[163] Pimmler and Eppinger (1994).

[164] Pimmler and Eppinger (1994), p.4.

replace, upgrade, place add-ons or disconnect a component, the irreversibility is relatively higher. This effort of reversibility can serve as a norm to determine the reversibility of an interface. This effort is dependent on two factors: the difficulty of physically disconnect the interface (effort) and secondly the position of the interface in the product architecture (depth).

The difficulty of disconnecting the interface represents the first value (fig. 10). The second value is represented by the depth in which an interface is 'buried' in the bus, i.e. how many components have to be removed before the component can be disconnected (fig. 10).

5.2.3 Interface standardization: determining an interfaces interchangeability

The interfaces' roles regarding component substitutes and product families, is the third interface category. Reason for its importance is that it is critical when an organization strives for product variety through standardization of component and interface. The strength and general idea of modular product architectures is the convenient way that sub-units can be exchanged.[165] This convenience works twofold, firstly through its reversibility, secondly the extent of alternatives available for exchange. In the literature different types of modularity have been classified using different characterizations of component interchanges. Component sharing, fabricate-to-fit, sectional and component swapping are the most often used characterizations.[166] The scholars define the characterizations as following. Component swapping and component sharing describe the alternatives existing on either side of the interface.[167] The title component sharing is used when the larger of two components is exchanged. When one component is set to remain in the system and the other component is switched the title component swapping is applied. Sectional modularity is used as a term when all units can interconnect. Fabricate-to-fit is applied when a component is constructed in a way that it will fit the existing interface.

[165] Fixson (2005).

[166] Ulrich and Tung (1991); Pine (1993); as well as Kusiak (1999).

[167] Fixson (2005).

Spatial		
Required:	(+2)	Physical adjacency is necessary for functionality.
Desired:	(+1)	Physical adjacency is beneficial, but not absolutely necessary for functionality.
Indifferent:	0	Physical adjacency does not affect functionality.
Undesired:	(-1)	Physical adjacency causes negative effects but does not prevent functionality.
Detrimental:	(-2)	Physical adjacency must be prevented to achieve functionality.
Energy		
Required:	(+2)	Energy adjacency is necessary for functionality.
Desired:	(+1)	Energy adjacency is beneficial, but not absolutely necessary for functionality.
Indifferent:	0	Energy adjacency does not affect functionality.
Undesired:	(-1)	Energy adjacency causes negative effects but does not prevent functionality.
Detrimental:	(-2)	Energy adjacency must be prevented to achieve functionality.
Information		
Required:	(+2)	Information adjacency is necessary for functionality.
Desired:	(+1)	Information adjacency is beneficial, but not absolutely necessary for functionality.
Indifferent:	0	Information adjacency does not affect functionality.
Undesired:	(-1)	Information adjacency causes negative effects but does not prevent functionality.
Detrimental:	(-2)	Information adjacency must be prevented to achieve functionality.
Materials		
Required:	(+2)	Materials adjacency is necessary for functionality.
Desired:	(+1)	Materials adjacency is beneficial, but not absolutely necessary for functionality.
Indifferent:	0	Materials adjacency does not affect functionality.
Undesired:	(-1)	Materials adjacency causes negative effects but does not prevent functionality.
Detrimental:	(-2)	Materials adjacency must be prevented to achieve functionality.

Fig. 5: General interaction quantification scheme

Source: Pimmler and Eppinger, (1994), p. 4

5.3 The FCA reducing product complexity across interfaces: how to cope with the organizational network externality influence

Established firms are often unsuccessful when coping with new architectures proceeded from new technologies.[168] The FCA methodology introduced by Ulrich and Eppinger[169] and further developed by Fixson[170] provides a useful tool for analyzing design decompositions. Design compositions of a highly engineered product such as The Whisper are suited for the FCA method. The indices 1 & 2 identify the number of components responsible for executing a function and the number of functions whom are influenced/dependent or by a component. The higher the rate of the indices-, represents a higher integrality which proves a stronger systemic character. "A modular architecture includes a one-to-one mapping from functional elements to physical components of the product, and specifies de-coupled interfaces between components. An integral architecture includes a complex (non one-to-one) mapping from functional elements to physical components and/or coupled interfaces between components."[171]

The decisions made in the product-architecture can have cross-domain influences on other organizations processes. "Using the framework in one or both of the ways described will help to develop a deeper understanding about the ways in which product architecture choices are linked to many decisions across the domains of product, process, and supply chain."[172] In order to provide insight in the network effects of these interfaces the table: *technological and organizational design decisions,* is connected to the framework.[173]

The effects that individual product architecture characteristics exert on the domain of the product covered by the FCA the research focuses on the effect on process and organization. These organizational effects next to those opposing the product architecture, instigated by the new components, are presented in table 1. It provides an overview of the components function and how it influences an organization to change or innovate in order to compatibilize/interconnect their interfaces. As stated, the new components do not only affect the product itself but also organizational process and other organizational segments for instance legislation and regulatory process.

[168] Henderson and Clark (1990).
[169] Ulrich and Eppinger (1994).
[170] Fixson (2005).
[171] Ulrich (1995), p. 422.
[172] Fixson (2005), p. 366.
[173] Fixson (2005), p. 367.

6. Applying the model to the Whisper: a systemic product architecture revealed

The existing literature provides considerable insight into product architecture and the introduction of systemic innovations. No methodology exists for the introduction of systemic innovations characterized by network externalities. Therefore this research focuses on expounding the knowledge on the introduction of systemic innovations characterized by network externalities.

Within this chapter the methodology introduced and elaborated upon is applied to the case of the Whisper bus. Figure 6 shows an overview of the complete network which is influenced by the innovations introduction. In order to visualize essential interactions between different stakeholders the network is protracted. Derived from the protracted network the innovation and its network are decomposed presented in figure 7, by a decomposition on product level. Finally analyzing the interaction between product elements and the architectural structure, this implies the level of a products modularity, or non-modularity. A design parameter is created linking this information with the function component relationship, presented in figure 8.

To demonstrate the systemic character of the standard and The Whisper bus are compared in the FCA-matrices. A matrix presents the impact of the innovation on the interfaces, by focusing at the product as well as the network externality effects on organizational components.

6.1 Introducing the Whisper case: finding the right partners for the project

The goals of the project demand the participation of powerful participants. The case in general, the impact on crucial participants in the project and the case are illustrated. The innovation demands from participants amongst other investments, a technological investment.

Veolia, Eneco, e-Traction, the Central Government, the Province of Gelderland and the municipality of Apeldoorn made the introduction of Whisper possible. The partners not directly participating in the Whisper Foundation but whom also fulfil an important role on the background are the suppliers: Ziehl-Abegg, Zapi, Intercontrol and Valence.

The project was made possible by major financial contribution from the Ministry of Transport, the province of Gelderland and the municipality of Apeldoorn. Next to a substantial financial contribution, the RDW facilitated in the process of law and regulation in order to permit public road access. Eneco places the junctions for charging the buses, delivers free Eneco Eco-electricity and supports the project with marketing and PR. Veolia transport bears the risk of integrating the buses in their timetable and indirect overhead expenses. Adjacent Veolia commences precious resources that are not available elsewhere and personally finances it. e-Traction invested approximately 5 million Euros in the development of the technology and contributes personally in the financing. e-Traction developed The Wheel, a wheel-nave motor. Unlike standard hybrid buses, the Whisper has a direct propulsion (direct drive), which provides a pure electric transmission of power to the rear wheels. Thereby constituting the wheel as a wheel nave motor without reduction, a propulsion with no mechanical transmission ceases to exist between the engine and the rear wheel.

As with any electric traction system, The Wheel needs to be supported by an energy system that matches the needs of the vehicle. Consisting out of a set of flexible modules the e-Traction system offers:

- Energy storage and supply;
- Axles, drive and suspension;
- Range extender and auxiliaries.

In order to storage and supply the energy all the vehicle engineered by e-Traction make us of Li-Ion batteries. As with every electric traction system one of the most critical and important components to be managed is the battery system. *"e-Traction has selected Valence as a reliable partner and preferred supplier in every application. Valence is the most reliable technology partner that e-Traction has worked with so far." (Heinen, director e-Traction)*

e-Traction put down a list of requirements which they demanded of a battery which is delivered by Valence. Resulting in a traction system with the delicate balance between state of charge, maximum current, voltage and battery weight optimised to reach maximum battery life and safe operation. *"Valence technology delivers superior battery quality and has proven reliable in projects such as the Whisper city bus. Its batteries have great advantages compared to conventional traction batteries." (Heinen, director e-Traction)* The charger of the battery is supplied by Zapi: "an European leader in high frequency motor controllers for battery powered machines. Providing "switching" battery chargers 'which are the most complete and flexible in use on the market"[174].

[174] http://www.e-Traction.nl/content_product_components_zivan.php

Co-operating with Ziehl-Abegg a motor range compatible with the Zapi AC inverters has been composed with e-Traction. “Flanges, brakes, axle-joints for transmissions, or for pump, steering- and traction is available”.[175] The Wheel is designed for bus application, thereby the axle designs are ready for integration in any type of city bus. Intercontrol Digsy supplies the computer to manage the dataflow. “Digsy Compact is an electronic automation system for mobile applications with data storage and integrated hydraulic control. CAN-bus with CANopen protocol and gateway functionality. Installation outside of vehicles is possible without any electrical cabinet.”[176]

6.2 Structure of the innovation: only institutions and customers as partners

The structure of systemic innovations are generally characterized by cooperation and development in the business market. Opposed to the general structure, the case of the Whisper bus is characterized by a public-private partnership (PPP). Cooperation with governmental organizations in development, deployment and implementation differs strong from the common.

“The foundation was established in order to prove the invention of e-Traction. (..) So Eneco as an energy supplier, the municipality of Apeldoorn, the county of Gelderland, and government as funding agencies, the passenger transportation company Veolia, are the main participants who made it possible.” (Hans Van der Ven, director The Whisper Foundation)

Based on the key factors that are relevant on the alliance evolution,[177] e-Traction has followed these steps successfully. In the formation phase the appropriate partners have been found, starting with the director of the Whisper Foundation. Followed by the design phase wherein appropriate governance to oversee the alliance is formed, a competent board of directors whom control and survey the project. And finally in the post-formation phase the alliance is managed on an ongoing basis to realize value.[178]

Revealed by the theoretical framework, (systemic) innovations generally are developed internal and introduced by one or a leading party. The Whisper differs due to its organization around the Whisper Foundation.

[175] http://www.e-Traction.nl/content_product_components_ziehl.php

[176] http://www.e-Traction.nl/content_product_components_plc_main.php

[177] Gulati (1998).

[178] Schreiner et al. (2009), p. 1402.

The Whisper project identified as a project and an alliance where benefits expected are identified, unclear remains the exact processes necessary to achieve them. In alliances as the Whisper Foundation partner commitment is more important than usual.[179] Partners must be- and have proved that they are- willing to dedicate costly resources to the relationship and pledge to work with each other realizing that some adaption is required in the future. Especially the input of the municipality Apeldoorn and Veolia are praiseworthy. The municipality Apeldoorn in the form of grants and Veolia in implementing the city-buses in their timetable with all its consequences.

"Due to juridical problems there was no possibility for investments nor grants in e-Traction. Therefore a foundation was founded, whereby the government could provide grants, the link between the legal defect and the grant provider has been cut off." (Van der Ven, director Whisper Foundation).

During the post-formation phase the development of trust and coordination is accomplished by introducing a heavy board of directors and installing a project team with key employees of every participating organization. The pitfall of insufficient knowledge about how actions are interdependent with others is neutralized by the foundations organization. Participants deliver their module/task and are controlled by the board of directors.

Programming, one of the three classic mechanisms to manage coordination successfully (is applied).[180] Clear guidelines are stated on what specific tasks need to be carried out by each partner, being exactly accountable for each task, and a timetable for implementing and delivering them. These guidelines improve clarity and predictability of partner actions, thereby reducing frustration and increasing decision making speed. Using the foundation as a filter relieves the first resiliencies and it operates as a independent institute. From this position, the foundation points out to parties their responsibilities, agreements are kept and potential conflicts are hampered.

"We have come to this as the solution for our issues concerning a potential world-class invention in an industry unwilling to change. Within the supply chain the core perishes, with 80% of all moving parts dropping out." (Van der Ven, director Whisper Foundation)

[179] Kale and Sing (2009), p. 48.

[180] Gailbraith (1977).

For governmental organizations it is walking on eggs when participating in a PPP regarding public support, the cooperation with a foundation is the right platform in order to communicate and justify their involvement.

Representing an overview of the complete network influenced by the innovation figure 6 provides clear insights. The network visualizes essential interactions between different stakeholders, the Whisper Foundation taking a central position within the network. The different stakeholders are interacting with each other and every stakeholder interacts with The Whisper. There exist globally four entities, consisting out of 1) governmental organizations, 2) suppliers, 3) community (not directly participating), 4) directly participating organizations. The dotted lines represent interactions within these four entities, the larger bold arrows represent the interaction from these four entities with The Whisper Foundation. There is more interaction as is presented between the stakeholders. In order to prevent a chaotic overview only the most decisive and effective relations are displayed.

"It is a possibility being launching customer. But some distance helps, and is necessary. If I would participate in such a process again, I would choose the same construction. A foundation with a supervisory board- with a clear division of responsibilities and a clear division of roles between the developer of the technique, the owner, and the potential marketing issues surrounding it." (Metz, Alderman municipality Apeldoorn)

The Whisper Foundation has an influential board of directors in order to create a publicly as well as a political supporting area. It operates as an autonomous administrative authority. As such it is able to operate and have the authority as a mediating structure. Every stakeholder is responsible for a component, the responsibility for coordinating these settlements lies with the Whisper Foundation. This results in the Whisper Foundation being a coordinating, auditing and mediating engagement partner.

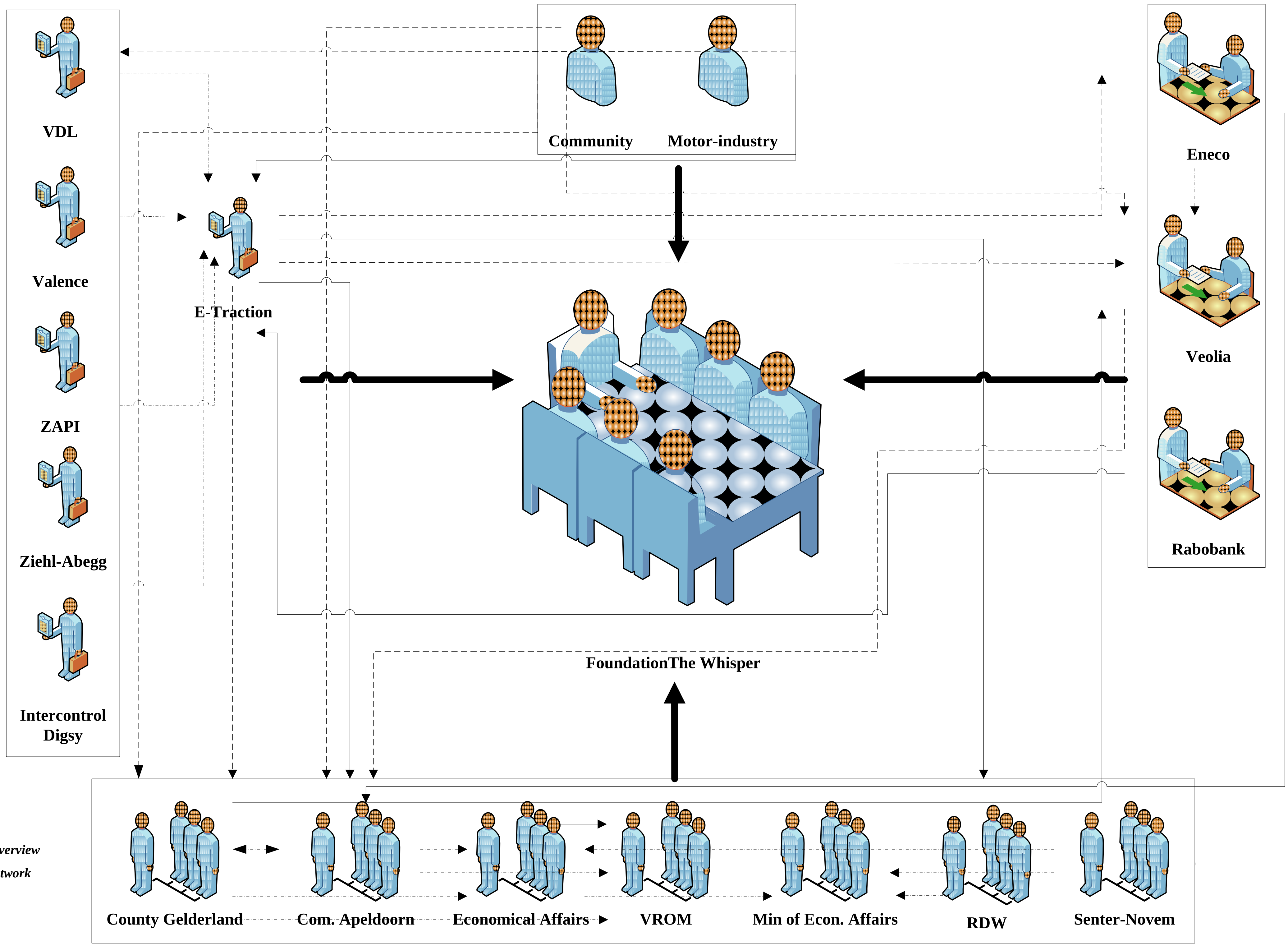

Fig. 6: Overview of the network

The flow diagram figure 7, represents at different function levels the underlying levels/functions of core components. These components function as well consecutive as simultaneously, as represented in the flow diagram. The simultaneously and consecutive operating from the components is an essential part in determining the systemic level of the innovation. Further elaborated in the following paragraph where the FCA matrices provide insight in this level of systemic.

A clear example of this simultaneously and consecutive operating is the instigation of energy. The mechanical energy provided by the diesel-engine is transformed through the generator set into electrical energy. This generated energy is supplied to the wheel nave motor or stored in the battery package. Compared to the standard situation the main difference consists out of the efficiency that The Whisper brings in generated energy not directly needed for the driving force being stored. As well in the function character being more systemic because the components are consecutive working on higher component levels.

Except the influence of the different components on a product level, the overall picture of the network combined with the function flow diagram present the influence of the different components on an organizational level. *"It is especially arranged according to a steering committee. Extra busses have been sent to Apeldoorn in order to bear possible fallout of busses." (Roel Van de Pas, Veolia)* Product characterizations also influenced on an organizational level by network externalities, especially when focusing on the energy management. The absence of a charger network, governmentally enabled and delivered and exploited by Eneco, embedded throughout the innovations infrastructure, negatively affects the innovations commercial possibilities. Although the energy sector is a private sector, there is a ground-breaking role for the governmental organizations in facilitating and integrate the refueling of the energy management in the infrastructure. Thereby contributing in the development of an installed base.

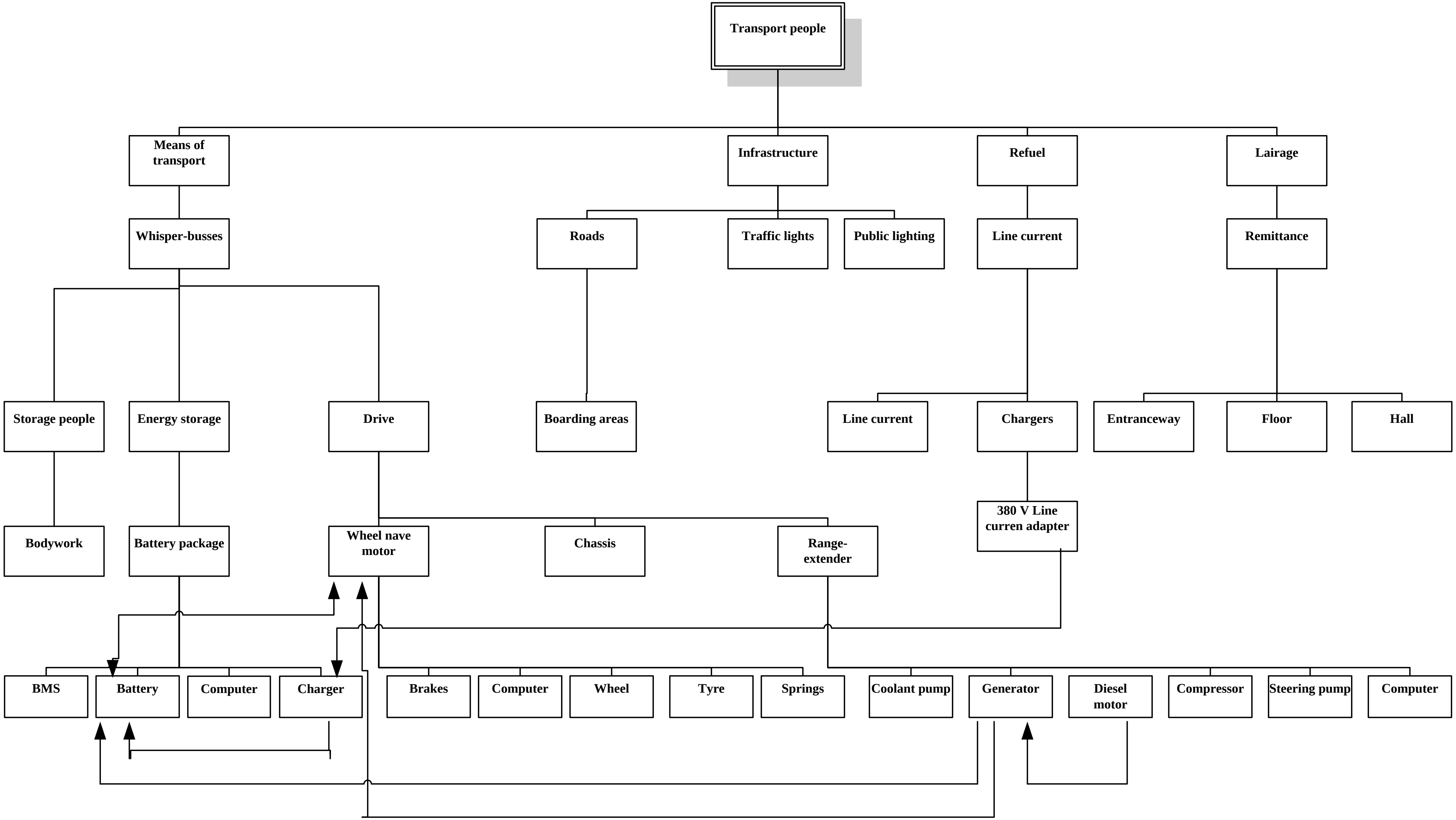

Fig. 7: Function levels decomposed components

6.3 Describing the systemic innovation: identifying interdepencies and coordinate specifications of new interfaces

The innovations systemic nature manifests itself mainly in the interaction between components performance of different functions. If several components provide a function which are also involved in providing other functions, a systemic character is revealed.

6.3.1 Function component matrix: analyzing product characteristics

The network in which the innovation is introduced, implemented and the different function levels it influences is illustrated by Figure 6 and 7. Figure 8 and figure 9 illustrate the function-component matrices for the two buses using the allocation procedure. The next step in determining the FCA is to calculate two indices for each function that shows how each function differs from the standard modular situation, which is represented by a low one-to-one relationship with a component.

By analyzing the product characteristics it becomes clear whether the product architecture is modular or non-modular (integral). "The extent to which a product architecture is modular, non-modular, is information that is required for each function and attribute individually. How exactly a function is different from the perfectly modular situation, by the one-to-one relationship between function and component is important knowledge."[181]

The two different indices reflect two possible different divergences in a relationship. The first index identifies the number of components that jointly provide a function. This index is calculated for each function in the column known as 'Index 1'. The second index identifies the extent to which the set of components, used for Index 1 also support other functions. In order to calculate this index, every component identified in index 1 are viewed and added up to the number of functions the component is jointly involved in. Counted up into the last column in the FCA matrix it is known as 'Index 2'. The more functions a component is jointly involved in leads to a more integral product architecture. Three components in the Whisper bus contribute in the function 'protection', therefore Index 1 = 3. Some of the components contributing in the function protection also contribute to the functions 'suspend structure', 'drive' and 'energy conversion' (Index 2 = 1 + 3 = 4 for the function 'protection').

The FCA matrices provide the overview and evidence that the new bus has a strong product architecture characterization. It is striking that in these two matrices, as seen in by indices 1

[181] Fixson (2005), p. 354.

and 2, there is more interaction to be seen between functions and components from The Whisper. The standard bus does not represent a “ideal modular” one-to-one mapping architecture, in contrary the Whisper is characterized as a more non-modular/integral architecture. Therefore the FCA matrices evidently show that the interaction between different modules and therefore the systemic character of the product is stronger represented within The Whisper opposed to a standard bus. Many of the components that are characterized as modular are being replaced by non-modular components.

“Many components are not implemented any more. For instance the differential and the sprocket-wheel are all being removed. Instead of these components others replace them.” (Roel Van de Pas, Veolia)

Overall the number of components that jointly provide a function (index 1) is even or has risen. Concerning the functions energy storage (f1), energy conversion (f2) and protection (f6) the components that jointly provide these function has risen with 1 component. Concerning index 2, the calculation of index 1 and the number of functions the component is involved in the same applies as to index 1, the number has risen or stayed even. Concerning the functions steering and suspend structure are equal as opposed to a standard bus. The functions energy storage, drive, electrics and protection have risen with 1. Meaning that for all these functions a component was involved in jointly providing one function more as opposed to the standard bus. Focusing on the function energy conversion it is striking that the components jointly responsible for providing the energy conversion are now involved in the performance of three other functions more, opposed to the standard bus. This results in a stronger integral product architecture, represented the strongest in a joint performance of energy conversion.

Components

	Functions	1 Engine	2 Diesel tank	3 Driveshaft	4 Electricalsystem	5 Brakes	6 Steering gears	7 Steering wheel	8 Suspensions	9 Carosserie	10 Bodywork	11 Battery	12 Clutches	13 Torque converters	14 Gearbox	15 Differential	16 Gas pump	17 Wheels	**Index 1**	**Index 2**
1	Energy storage		1									1					1		2	2
2	Energy convertion	1		1															2	2
3	Drive			1		1							1	1	1	1		1	7	3
4	Steering						1	1										1	3	2
5	Electrics				1							1							2	2
6	Protection								1		1								2	2
7	Suspend structure								1	1									2	2
	Function count	1	1	2	1	1	1	1	2	1	1	2	1	1	1	1	1	2		

Fig. 8: Function component matrix standard bus
Source: Fixson (2005), p. 355

Components

	Functions	1 Engine	2 Diesel tank	3 Driveshaft	4 Electrical system	5 Brakes	6 Steering gears	7 Steering wheel	8 Suspensions	9 Carosserie	10 Bodywork	11 Wheels	12 Gearbox	13 Chargers	14 Line current	15 Generator set	16 The Wheel (nave motor)	17 Battery package	18 Range-extender	**Index 1**	**Index 2**
1	Energy storage		1											1	1			1		4	3
2	Energy convertion	1		1												1	1	1	1	6	5
3	Drive			1		1						1	1			1	1		1	7	4
4	Steering						1	1				1								3	2
5	Electrics				1													1		2	3
6	Protection								1		1						1			3	3
7	Suspend structure								1	1										2	2
	Function count	1	1	2	1	1	1	1	2	1	1	2	1	1	1	2	3	3	2		

Fig. 9: Function component matrix Whisper bus
Source: Fixson (2005), p.355

6.3.2 Product architecture assessment: defining interface characteristics

A products interface characteristics are often described with terms such as 'coupled' or 'dependent'. The interfaces' roles for the product function, i.e. their types, are determined by their nature, number and reversibility. The theoretical background of the interface assessment has been amplified in chapter 5.1. the interface matrices for the two buses are represented in figure 10.

"We have completely pulled it apart and therefore it now becomes separate parts electrically linked together. That is the big difference, and furthermore all these systems are integrated." (Arjan Heinen, director e-Traction)

Due to their mechanical characteristics, most of the interfaces of both buses are spatial. Overall the Whisper bus has a higher interaction between interfaces and a higher number of interfaces in total. The number interfaces (46) expressed as a percentage of the theoretical maximum number of interfaces (136) shows that there is an increase of over 4%. The standard bus having a percentage of 33.82% and the Whisper bus 37.9%.

The higher interaction between interfaces applies to three out of four forms considered.[182] Only on material interaction, the need for the exchange of materials, both buses score a 0. Meaning that there is no need for the exchange of materials between interfaces in both buses. Adjacent to the number of interfaces their characteristics show that the product architecture of the Whisper bus has a more integral character opposed to the product architecture of a standard bus. Based on the general quantification scheme presented in fig. 5 the SIEM demonstrates the systemic character.[183] A higher intensity of these interactions demonstrates a higher integral character. The standard bus has a total Spatial interactions of 74 vs. 84 in the Whisper bus, hence an increase of 10 is established. This increase also applies to Information (+24) and Energy (+13).

Note that despite the differences in the FCA schemes, both architectures do still exhibit a number of similarities with respect to the type of interfaces. The Whisper bus represents a significant higher score on energy and information. The components who differ from the standard bus can be considered to have a greater need for energy transfer and a need for information or signal exchange between two elements.

[182] Pimmler and Eppinger (1994).

[183] Pimmler and Eppinger (1994).

It is clear that the new components such as the wheel nave motor and range extender interacts with a significant number of other components (relative to the total number of components) represented in fig. 9 & 11, playing a pivotal role in the product architecture. The wheel nave motor is a component which signals a central component supplying and generating general functionality. The Whisper which has many components that show interactions with many other components, displayed in figure 11, therefore it is more integral.

6.3.3 Product architecture assessment: interface reversibility how deep is the component 'buried' in the product

The second interface characteristic analyzed is the interfaces 'reversibility', amplified in chapter 5.2.2. interface type irreversibility.

Opposed to the standard bus the number of interfaces of the Whisper are more numerous. Accounted for by the addition and replacement of several new components added to the Whisper bus.

The results for the two buses are shown in the lower triangles of the matrices in figure 10. With respect to the difficulty to reverse, most of the interfaces are similar. This goes as far as the components consistent in both buses. Characterized by the addition of several components the reversibility of the Whisper bus is lower opposed to a standard bus. The criteria to assess effort to disconnect interfaces of the standard bus are considered overall low-medium. Whereas the product architecture of the Whisper bus, especially considering the additive components, the criteria to assess effort to disconnect an interface as medium-high. The systemic character is strengthened, due that "the notion of various product changes over the product life, such as upgrades, add-ons, adaptation, wear, consumption, or reuse – which are often assumed as being one of the major advantages of modular product architectures – strongly depends on the reversibility of the interface."[184]

The Whisper exhibits significant 'depth' composed to the standard bus in which of the interfaces are 'buried' within the product. Note, that especially the additional/deviant components interfaces are 'buried' in the product. If these components were to be replaced it would require disconnecting several of the relevant interfaces.

[184] Fixson (2005), p.359.

Standard bus	1 Engine	2 Dieseltank	3 Driveshaft	4 Electrical system	5 Brakes	6 Steering gears	7 Steering wheel	8 Suspensions	9 Carosserie	10 Bodywork	11 Battery	12 Clutches	13 Torque convertors	14 Gearbox	15 Differential	16 Gas pump	17 Wheels
1 Engine		1 2 0 0	1 1 0 0						2 0 0 0	1 0 0 0	2 1 0 0			2 1 2 0		2 1 0 0	
2 Dieseltank	3 3								1 0 0 0	1 0 0 0							
3 Driveshaft	2 2								2 0 0 0					2 2 2 0	2 2 1 0		
4 Electrical systems									1 0 0 0		2 2 2 0						
5 Brakes										2 0 0 0							2 0 2 0
6 Steering gears									1 0 0 0	2 0 1 0							2 0 1 0
7 Steering wheel										2 0 1 0							2 0 1 0
8 Suspensions									2 0 0 0	2 0 0 0							2 0 0 0
9 Carosserie	3 3	3 2	2 2	1 1		2 2		2 2		2 0 0 0	2 0 0 0	1 0 0 0	1 0 0 0	1 0 0 0	2 0 0 0		2 0 0 0
10 Bodywork	1 1	1 1			1 1	2 1	2 2	1 1	1 1		2 0 0 0	1 0 0 0	1 0 0 0	2 0 0 0	1 0 0 0	2 0 0 0	2 0 0 0
11 Battery	2 2			1 2					1 1	1 1				2 1 1 0	1 0 1 0		
12 Clutches									3 2	1 1				2 1 0 0	2 1 0 0		
13 Torque convertors									2 2	1 1				2 1 0 0	2 1 0 0		
14 Gearbox	3 2		2 2						3 3	1 1	3 2	3 3	2 2				0 1 1 0
15 Differential			2 2						2 2	1 1	1 2	2 2	2 2				2 2 0 0
16 Gas pump	2 3									1 1							
17 Wheels					1 2	2 1	2 1	1 2	1 1	1 1				1 1	1 1		

REVERSIBILITY of Interfaces (lower triangle)

Effort 1
Depth 1

Effort to reverse		*Depth in which interface is located*	
easy	1	shallow	1
medium	2	medium	2
difficult	3	deep	3

NATURE of Interfaces (upper triangle)

Catergory: Spatial S E Energy
Information I M Materials

Intensity

Required	2
Desired	1
Indifferent	0
Undesired	-1
Detrimental	-2

NUMBER of Interfaces

theoretical max	136
theoretical min	16
real	46

Figure 10. Interface matrices

Source: Fixson (2005), p. 358

Whisper	1 Engine	2 Diesel tank	3 Driveshaft	4 Electrical system	5 Brakes	6 Steering gears	7 Steering wheel	8 Suspensions	9 Carosserie	10 Bodywork	11 Wheels	12 Gearbox	13 Chargers	14 Line current	15 Generator set	16 The Wheel (nave motor)	17 Battery module	18 Range-extender
1 Engine	\	1 2 0 0	1 1 0 0						2 0 0 0	1 0 0 0		2 1 2 0				0 2 1 0	1 1 2 0	2 2 1 0
2 Dieseltank	3 3	\							1 0 0 0	1 0 0 0								1 1 0 0
3 Driveshaft	2 2		\						2 0 0 0			2 2 2 0				1 2 1 0		2 1 2 0
4 Electrical system				\						1 0 0 0						1 1 1 0	2 2 2 0	1 1 1 0
5 Brakes					\					2 0 2 0	2 0 2 0					2 1 1 0		
6 Steering gears						\			1 0 0 0	2 0 1 0	2 0 1 0							
7 Steering wheel							\			2 0 1 0	2 0 1 0							
8 Suspensions								\	2 0 0 0	2 0 0 0	2 0 0 0							
9 Carosserie	3 3	3 2	2 1			2 2		2 2	\	2 0 0 0	2 0 0 0	1 0 0 0	1 0 0 0		1 0 0 0	2 0 0 0	2 0 0 0	2 0 0 0
10 Bodywork	1 1	1 1	1 1	1 1	1 1	2 1	2 2	1 1	1 1	\	1 0 0 0	2 0 0 0	1 0 0 0		1 0 0 0	1 0 0 0	2 0 0 0	1 0 0 0
11 Wheels			1 1		1 2	2 1	2 1	1 2	1 1	1 1	\	0 1 1 0				2 1 1 0		1 0 0 0
12 Gearbox	3 3		2 2						3 3	1 2	2 1	\					2 1 1 0	
13 Chargers									2 1	1 1			\			0 0 1 0	2 2 1 0	2 1 2 0
14 Line current														\			1 2 1 1	1 0 1 0
15 Generator set									3 3	1 1					\	1 2 1 0		2 2 2 0
16 The Wheel (nave motor)	2 1		2 1	2 2	2 2				3 3	1 1					2 3	\	0 2 2 0	1 2 2 0
17 Battery module	1 2			3 3					3 1	1 1		3 3	2 2	2 3		2 2	\	2 2 2 0
18 Range-extender	3 3	1 1	2 1	3 2					3 3	1 1	1 1		1 2	2 3	2 3	3 3	3 3	\

REVERSIBILITY of Interfaces (lower traingle)

Effort	1
Depth	1

Effort to reverse		*Depth in which interface is located*	
easy	1	shallow	1
medium	2	medium	2
difficult	3	deep	3

NATURE of Interfaces (upper triangle):

Category:

Spatial	S	E	Energy
Information	I	M	Materials

Intensity

Required	2
Desired	1
Indifferent	0
Undesired	-1
Detrimental	-2

NUMBER of Interfaces

theoretical max	153
theoretical min	17
real	58

Figure 11. Interface matrices

Source: Fixson (2005), p. 358

6.3.4 Introduction of the innovation: breaking through the excess inertia by compatible interfaces

As identified the degree of systemic characterization does not show a difference in the general interaction quantification regarding all components, especially concerning the components present in both buses. Nevertheless, there is a great influence exercised on the interfaces and organizations involved. Table 1 provides the liaison between the technology (the interface) and the organizational design decisions.

"The busses whom we charge are connected with a standard 380w cable coupler. This is applicable with the current infrastructure. Waiting until the electrical charging stations are implemented is no option, without electrical cars there are no charging stations and vice versa" (Arjan Heinen, director e-Traction)

The leading invention inside the innovation is The Wheel nave motor. By implementing The Wheel nave motor e-Traction will have to develop the soft- and hardware and share their knowledge. The sharing of knowledge is done by training customer mechanics. Sharing the knowledge creates a greater understanding of the invention and will instigate a greater supporting ground.

Next to the innovation itself it has to prove itself, there are several boundary conditions that need to be supportive. When commencing the buses into the traffic and implement them in the organizations fleet it is necessary that they are insurable and allowed on the public road. In which there is an important role for the governmental decision makers in order to make it possible.

"There is a huge risk independent from the technology itself. The biggest risk lies with the technology, but when you look at the complexity surrounding the start-up of such a project. Starting with the fact that you do not get a liability insurance." Van der Ven, (Director, Whisper Foundation)

The influence of network externalities manifests itself most clearly in the energy management. A vehicle dependent on electrical energy needs a charging station within reach. Hence it concerns a city bus, therefore a charging station in the car barn is sufficient. Although when the technique is broadly grounded it is important that it has a broader coverage. Eneco developed a charging station delivering energy to the electrical driven vehicles. E-Traction already made the interface of the bus compatible with the industry standard, therefore Eneco needs to provide a network of charging stations (installed base). Compatible general governments interest in a durable automotive solution.

"It will work with the current infrastructure. That is our basic assumption. For if we have to wait for charging stations to be placed everywhere, it is the classical chicken-egg story. There is no charging station, therefore you still have no electric cars and due to the absence of electrical cars there is no interest in placing charging stations, we're not going to wait on it. (Arjan Heinen , director e-Traction)

As displayed in table 1, the several added components have an impact both within the product and its interface as on the organizations involved in the Whisper project. The influence and characterization of network externalities reveals itself in how to cope with the products energy demand.

Component: technological performance	Interfaces involved in jointly performance of functions	Organizational impact
Charger: element in an infrastructure that supplies electric energy for the recharging of electric vehicles.	380 V AC Line-current adapter: the adapters interfaces are compatible with the current energy infrastructure. Therefore the transfer of energy to the bus is widely possible, thereby enlarging the deplorability of the Whisper bus.	Eneco implements charging stations at bus depots which fall under Veolia supervision. A new electrical installation is developed and implemented in the bus depots. The buses refurbished by e-Traction become compatible with these interfaces to be consistent with the charging stations. The municipality of Apeldoorn provides all licenses, as well as stimulating other municipalities in facilitating the possibilities of electrical charging.
Generator: mechanical energy generated by the generator set is transformed into electrical energy. This energy is delivered directly to the engines, or used to recharge the battery set.	CANopen programmable logic computer forms the link between all components and are jointly governed by the e-Traction Energy Management System software.	The development of the generator by suppliers and the software developed by e-Traction provides a higher performance. E-Traction triggers suppliers in developing better performing generators.
The Wheel (nave motor): wheel motors are applied in driving the vehicle. An internal system ensures adequate coordination to regulate acceleration and speed of the wheels. The electric motors when braking return energy to the battery.	CANopen programmable computer forms the link between all these components which are jointly governed by the e-Traction Energy Management System software.	The government, (RDW) ensures that the Whisper is permitted to drive on the public road. e-Traction designs the wheel nave motor in a way that it is compatible into a standard city bus product platform. Veolia implements and thereby tests the buses in their itineraries.
Battery: The individually CANopen controlled battery functions primarily as the buffer between demand and supply. It also functions as storage device for regenerative braking energy.	CANopen programmable logic computer forms the link between all components and are jointly governed by the e-Traction Energy Management System software	E-Traction implementing the battery set into the Whisper. Needs to stimulate their suppliers in order to develop stronger batteries.
Range-extender: apllied for generating electricity from the cleanest possible combustion.	CANopen programmable logic computer links all components and are jointly governed by the e-Traction Energy Management System software.	Government sets stringent measures and regulations concerning the emission output. Enforcing these measures instigates sustainable innovations as The Wheel, gaining market acceptance.

Table 1: Technological and organizational design decisions

Based on: Fixson (2005, p. 367)

The busses range are limited by where they are able to subtract electrical energy from the line current. In the Whisper case the parties involved, preceded by e-Traction, have introduced the government as a partner in order to break through the excess inertia. Figure 11 displays the moderating effect of network externalities on the innovations introduction. The government has the force and the means to provide the installed base. Using the installed base provided by the government or Eneco, a network of charging stations at all bus barns the innovation can be introduced and nationally unfolded. When the network is internationally adopted and providing international charging stations, the innovation can spread out as an oil slick. In the Whisper case the government is used as a vehicle to introduce the innovation. Therefore, rather than seeing the government as a restrictive partner the Whisper Foundation has transformed the government in a constructive partner.

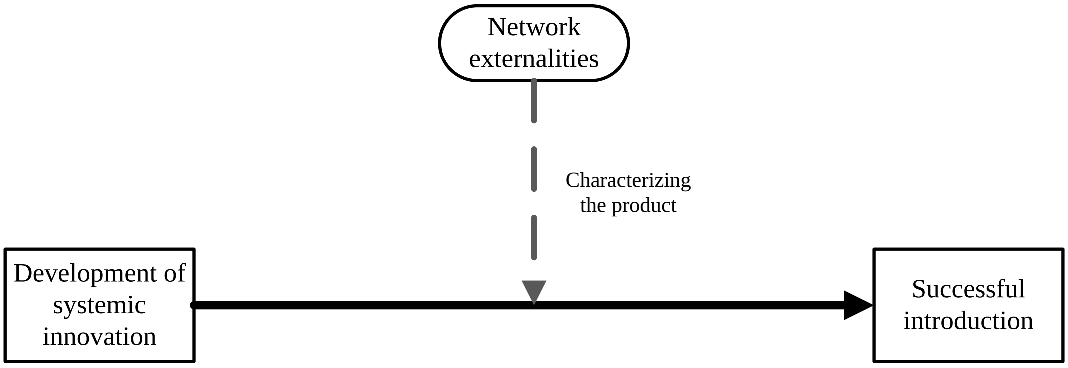

Figure 11. moderating effect of network externalities

Next to the compatibility of the organizational processes and regulations there has been a technological focus. As emerged in the preceding chapters on the technological basis the influence of the network externalities has been restricted due to interfaces whom are compatibalized with the present technical infrastructure.

“You try to create interests. I do nothing more than creating demand, but it needs to be validated.” (Metz, alderman Apeldoorn)

6.4 The process of development and introduction of the Whisper bus

Innovations are characterized by the variety of fluctuations in pace. Applied to the Whisper case it is at full speed or standing still with the prospect of steady progress. This also applies to other unprecedented technological systemic innovation, also called a ‘step change’. Innovation means discovering not only in technological terms but also in how you work with other parties trying to pursue combined goals. Therefore, the Whisper already remarkable, is an example of a public-private partnership.

"As the municipality of Apeldoorn there are being set up investment programs in order to stimulate electrical transportation." (Cevaal Douma, project concultant municipality Apeldoorn)

Innovations in electric transport are at the order of the day, overwhelmed with publicity. After a long development phase a very complex innovative product The Wheel, with a huge potential application in practice on his merits, is introduced. With the public transport passenger market, it had a rock-hard critical jury, as the ultimate test.

The innovation thrives on the invention of The Wheel, a wheel nave driven motor. The Wheel as a laboratory-type invention utilized in The Whisper and further developed in conjunction with other components. Decisive is collaboration with various parties, both at government level and the corporate market. Within the supply chain there is intense horizontal (stakeholders) and vertical (suppliers, customers) cooperation, all coordinated within the Whisper Foundation.

"In coordinating such a project you need a strong coordinator. Mostly an external consultant is asked for the job. Whom coordinates the project and make sure that all the administrative tasks and the like." (Dubbeld, department of Economical Affairs)

Knowledge about the applicability and usability of the product is accumulated through product knowledge i.e. through training customer technicians. By sharing knowledge, one hopes to receive more knowledge in the products applicability and how the innovation reacts to different conditions. Thereby providing information of inestimable value on the product and its abilities.

"We are not afraid to share knowledge. Currently people are trained from Korea and Sweden on how to built a bus using our invention." (Arjan Heinen, director e-Traction)

In the product introduction there is deliberately chosen to approach the government. The main reason for approaching the government are the absence of direct commercial interests. In addition, they are committed to projects with a long lead time, usually the case with (systemic) innovations like The Whisper.

"The main reason for choosing busses is to create visibility and the government has great interests." (Arjan Heinen, director e-Traction)

Three striking examples from the field of practice on how the collaboration was between the participating parties and their involvement are:

1. The engineering of a innovation such the Whisper is relatively time-consuming. It is due to a truly exceptional step of the municipality of Apeldoorn that prematurely engineering was able. The municipality provided funding, while the overall project in central authorities was still awaiting approval. Such decisiveness is extremely peculiar in the bureaucratic Netherlands.
2. As a public transportation company Veolia is backing up the project fully, but what would there incentives be? Veolia earns their businesses by providing the best tender at license grants. In recent years the Dutch public transportation companies have been squeezed greatly by the licensing authorities, which brought fierce competition, thereby leaving little room for research and development. Participating in innovative projects as such are to a carrier additional costs incurred by irregularity, additional losses due to fallout ratio and higher inefficiency. Nevertheless Veolia is highly motivated along with project The Whisper, inspired by the philosophy that Veolia on the long term, as the world his largest public transport company, can only be successful if they remain to provide safe and sustainable mobility solutions. Therefore the Whisper project is closely monitored.
3. As a corollary to the business partners the government has played a huge role in the project. The ministry of infrastructure and environment and the county Gelderland. The Whisper Foundation received a contribution of both and without the size of the amount provided the foundation would not even have been founded. The government policy has stimulated and worked.

The integral character of the component The Wheel in the implementation of the bus requires changes in other parts of the product as well on other organizations. The wheel nave motor requires a technological investment of suppliers and participants in the network. In order to storage and supply the energy a battery package adjacent to the requirements is developed by suppliers. The innovation also requires a dataflow within the system, therefore a electronic system is essential, developed and implemented in the innovation.

The energy requirement of the vehicle characterizes the network externality impact. A network of junctions for charging the buses. Without these charging stations the bus is not able to be implemented in a timetable. In order to implement the innovation in the general city-bus market a network of charging stations is required. The lack of a network of charging stations (installed base) is the shortfall in order to break through the excess inertia.

Next to the technological investment the systemic innovation requires adaptations in general regulation to implement the innovation in the timetable of Veolia.

7. Summarizing and linking the findings: laboratory-type innovation process with limited partner involvement as a challenge

It is clear that the Whisper is a textbook example of a public private partnership. Not without reason, this issue is forwarded separately. In general the public has no idea what organizational, technical, financial, transport technical approvals, insurance and other obstacles must be overcome in order to commencing a single bus. Only due to the fact that a group of partners – from completely different backgrounds and manifold incentives- had the consent to put in their best efforts in order to let the project succeed.

A central element in determining the systemic character of the innovation is the product architecture concept, represented by the FCA method.[185] By focusing on the number of interfaces and the interactions between interfaces the degree of the systemic character is determined. Applying the model proved to be a practicable method in determining the systemic (integral) character and the degree of modularity. The existing theory is almost complete but a gap still exists in the organizational consequences the linking of interfaces practices. Hereby exposing the influence that network externalities practise on both the product characteristics and the organization(s).

The theoretical method has been applied by decomposing an innovation into its components and the functions performed by these components. By identifying and classifying the product his interface characteristics the (integral) systemic character of the innovation became clear.

Applying the model to the Whisper case it became clear that the integrality of the innovation is high, for it has strong interfaces and a low reversibility. Resulting in a strong difference between a modular innovation or an integral and systemic innovation. The product architecture of the Whisper is characterized by a systemic and integral product architecture. Because it is integrated and buried deep in the product his architecture it resembles strong systemic characteristics. The side-effects of network externalities are minimized by adapting the interfaces to the current infrastructure. In order to evolve the innovation and implement it on a larger scale it is inevitable to adjust the infrastructure and break through the excess inertia by creating a greater installed base.

[185] Fixson (2005); Pimmler and Eppinger (1994).

7.1 Theoretical implications: For model development and knowledge gained on systemic innovations characterized by network externalities

Radical innovations which change core technical concepts and their linkages lead to adaptive challenges for organizations.[186] Therefore, there is an increased number of papers about the impact of radical innovations on product architecture[187] and recognizing the influence of systemic innovations.[188] Focusing on systemic innovation in relation to product design, supplier management, information technology. One of the first scholars to provide insights in how to break through the excess inertia are Dew and Read.[189] Still a literature gap exists on how to introduce a systemic innovation characterized by network externalities.

In this study a conceptual model is tested in order to expand the existing literature by focusing on the introduction this type of innovation. Thereby the study contributes to the systemic innovation literature twofold. First by analyzing the influence of network externalities on the introduction of a systemic innovation and secondly introducing the entity of a foundation in order to coordinate a PPP cooperation. In managing a PPP cooperation a foundation serves as an outstanding equity based alliance form. Partner commitment rises and the governmental participants are able to offer grants without the apparent conflict of interest.

Since innovations are not all ready to copy one-on-one, not all introductions of (systemic) innovations should be managed similarly, especially when characterized by network externalities. When introducing a network externality product it is inevitable to either invest the installed base or enhance the product value.[190]

This study suggests that breaking through the excess inertia the government forms an exceptionally good partner. The findings implicated that in order to break through the excess inertia induced by network externalities it is possible to weaken the effects by adjusting interfaces to the existing infrastructure.[191] The findings also suggests that when cooperating with a governmental organization it is necessary to establish an independent entity. An independent entity works as a mediating factor between the parties involved and facilitates that all parties involved are able to focus on their core business.

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[186] Tushman and Anderson (1986).

[187] Pimmler and Eppinger (1994); Fixson (2005).

[188] Henderson and Clark (1990); Linkvist et al. (1998); as well as Magnusson et al. (2002).

[189] Dew and Read (2007).

[190] Dew and Read (2005).

[191] Dew and Read (2007).

7.2 Managerial implications: a general, private cooperation vital for the introduction

Based on the study its findings, several managerial recommendations are developed. First of all, the research findings suggest that in order to introduce a systemic innovation-characterized by network externalities- an installed base or product value is essential. Coping with the introduction of a case with similar characteristics as the Whisper case, an installed base is essential. At the same time, the product value met sufficient conditions and at the same not appropriate due to the lack of possibilities by the inventing firm to enter into mass-production.

The implication is that firms should engage in a PPP when the introduction of their product has a long lead time before it is fully applicable in the market and meets customer demands. Due to the fact that a government serves public interests instead of commercial. Thereby implicating that a governmental partner is reliable in creating the installed base necessary to break through the excess inertia. Next to the conditions in order to launch the innovation, a government cannot provide subsidiaries directly to organizations, an independent entity where both parties are represented in the form of a foundation serves as an outcome.

Moreover the findings suggest that the coordination of the product through a foundation is an effective vehicle when introducing a systemic innovation. The coordinating and moderating effect of a foundation, that contributes in creating deeper understanding and the influencing of decisions across product domains, such as organizational and regulatory process. Complemented with a high social standing provide a broad support in order to market the product.

7.4 Future research and limitations

While the product architecture framework produces a promising result on innovation influenced by network externalities the research field finds itself in an early stage. Endorsed by a general market becoming more influenced by network externalities it provides a perfect ground for research focusing on small ventures launching systemic innovative products or services. The governmental role has been restricted to a regional and more or less national role, therefore future research could involve more focus on national or international governmental cooperation.

This research has focused on the collaboration between government and the private sector. Hopefully this study will assist in the introduction of a systemic innovation characterized by network externalities. Moreover that the research will trigger scholars in future examining the introduction of equivalent innovations characterized by network externalities.

Limitations

Despite the care taken at the different stages of this study, there are still several limitations that need to be taken into account by interpreting the findings. First, by choosing to focus on The Whisper- an innovation introduced in the automotive industry, there is a danger to generalize the study its findings to other industries. Future research is necessary in order to generalize the findings in a brother perspective.

The second limitation concerns governmental cooperation. The governmental influence and national legislation provided will not be identical in every municipality, county or on a higher level country. Therefore it is important when selecting the case that these factors are taken into account and especially the grant provided could influence the objectivity.

Thirdly, the research had to deal with the time-frame in which the research is done. In the case study of The Whisper it concerns an introduction, but the project is not finished. Although aware that the timeframe (2010) may be too short to call the case a definite success all indications give a positive implication. Therefore future researchers are suggested to select a case which is completed.

Final limitation is that the organization that founded the core element of the innovation are not able to mass-produce the innovation. As a result the research could not asses how the market and organizations respond, had the innovation be commercialized on a larger scale.

Despite these limitations, the research has provided interesting insight in the introduction of a systemic innovation characterized by network externalities. Hopefully this study will provide managers and parties concerned new insights and a method in order to introduce similar innovations. As well as other scholars inspiration to conduct a follow-up research in order to gain more insight in systemic innovation.

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Appendix 1: Patent The Wheel

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CROSS-REFERENCE TO RELATED APPLICATIONS

The present application is a continuation of International Application Number PCT/NL01/00054, filed Jan. 26, 2001, which claims the benefit of NL application Ser. No. 1014182, filed Jan. 26, 2000, both of which are hereby incorporated by reference in their entirety. International Application Number PCT/NL01/00054 was published in English under PCT Article 21(2) on Aug. 2, 2001 under International Publication Number WO 01/54939.

Claims:
The invention claimed is:

1. A wheel comprising: an electric motor including a rotor and a stator with windings; control means for controlling power in the electric motor, wherein the control means is rotationally fixed to the stator; an accommodation space inside the wheel, wherein the accommodation space houses the control means; at least one measurement tool, coupled to the control means, wherein said at least one measurement tool measures a number of revolutions and an angular position of the rotor with respect to the stator and a current through the windings; operating means, connected to the control means and responsive to the number of revolutions and the angular position of the rotor with respect to the stator output from the at least one measurement tool, for operating the wheel; data communication means, connected to the operating means, for communicating data outside the wheel; a cooling fluid input port, a cooling fluid output port, and a cooling fluid circulation space within the wheel, wherein cooling fluid provided through the input port circulates through the cooling fluid circulation space and is output through the cooling fluid output port in order to cool the windings and a wall of the accommodation space during operation of the wheel; wherein the electric motor directly drives the wheel; and the electric motor, the control means, the at least one measurement tool, the operating means and the data communications means are situated inside the wheel; and wherein the wheel has an exterior surface perpendicular to an axis of rotation of the wheel, and the cooling fluid input port and the cooling fluid output port pass through the exterior surface of the wheel.

2. A Wheel according to claim 1, in which the wheel comprises a rim which coaxially at an inner side is provided with the rotor, the rotor at the inner side being provided with permanent magnets, the stator being situated coaxially with respect to the rotor and being connected to a vehicle.

3. A Wheel according to claim 1, wherein the data communication means are adapted for exchanging data with control means, measurement tools and operating means of other, similar wheels.

4. A Wheel according to claim 1, in which the data communication means comprise optical communication means.

5. A Wheel according to claim 1, in which the at least one measurement tool, the control means and the operating means communicate via a central processing unit outside the wheel.

6. A Wheel according to claim 1, in which the operating means are connected to a central processing unit outside the wheel by means of the data communication means.

7. A Wheel according to claim 1, provided with fans in the wheel for cooling the wheel.

8. A Wheel according to claim 1, further comprising means for measuring mechanically delivered torque and means for measuring the torque by measuring electrically accommodated power, and means for comparing the mechanically delivered torque and the electrically accommodated power.

9. A Wheel according to claim 1, in which an operating system in the wheel is provided with a master setting and a slave setting, in which by means of the data communication means a central processing unit is able to have the operating means switch from the master setting to the slave setting and vice versa.

10. A Wheel according to claim 1, the control means, the at least one measurement tool, the operating means and the data communication means are situated inside the stator.

11. A Wheel according to claim 2, in which the stator is divided into at least two groups of electrically and physically separated windings and each group comprising at least two windings each having their own control means and at least one measurement tool operated by operating means situated inside the wheel.

12. A Wheel according to claim 2, further comprising a cooling body provided with means for holding heat-producing electronic components of the control means and the operating means in heat-exchanging contact with the cooling body, the cooling body being mounted in heat-exchanging contact with the stator.

13. A Wheel according to claim 2, wherein the rotor is connected to a central shaft and the stator is situated coaxially with respect to the central shaft between the central shaft and the rotor.

14. A Wheel according to claim 9, in which the switch from the master setting to the slave setting and vice versa is influenced by either power demand or speed of the wheel.

15. A Wheel according to claim 9, in which the wheel is set to the master setting when the wheel demands the lowest power of similar wheels associated with a vehicle.

16. A Wheel according to claim 11, in which the control means comprises means for controlling amperage through each of the windings separately.

17. A Wheel according to claim 11, wherein the control means comprise power modules coupled to the windings, and power regulators coupled to the power modules and to the device for measuring current though the windings.

18. A Wheel according to claim 11, wherein the control means comprises two power modules coupled to each winding and a power regulator coupled to said two power modules.

19. A Wheel comprising: an electric motor located inside the wheel, the electric motor including a rotor and a stator with windings; control means located inside the wheel for controlling power in the electric motor, wherein the control means is rotationally fixed to the stator; an accommodation space inside the wheel, wherein the accommodation space houses the control means; at least one measurement tool, coupled to the control means, wherein said at least one measurement tool measures a number of revolutions and an angular position of the rotor with respect to the stator and a current through the windings; operating means located inside the wheel connected to the control means and responsive to the number of revolutions and an the angular position of the rotor with respect to the stator output from the at least one measurement tool, for operating the wheel; data communication means located inside the wheel and connected to the operating means, for communicating data outside the wheel; and a cooling fluid input port, a cooling fluid output port, and a cooling fluid circulation space within the wheel, wherein cooling fluid provided through the input port circulates through the cooling fluid circulation space and is output through the cooling fluid output port in order to cool the windings and a wall of the accommodation space during operation of the wheel; wherein the wheel has an exterior surface perpendicular to an axis of rotation of the wheel, and the cooling fluid input port and the cooling fluid output port pass through the exterior surface of the wheel; wherein the electric motor directly drives the wheel.

20. A Wheel comprising: an electric motor located inside the wheel, the electric motor including a rotor and a stator with windings; a controller, located inside the wheel, that controls power in the electric motor, wherein the controller is rotationally fixed to the stator; an accommodation space inside the wheel, wherein the accommodation space houses the controller; at least one measurement tool, coupled to the controller, that measures a number of revolutions and an angular position of the rotor with respect to the stator and a current through the windings; a module, located inside the wheel, connected to the controller and responsive to the number of revolutions and the angular position of the rotor with respect to the stator output from the at least one measurement tool, that operates the wheel; a data communication link located at least in part inside the wheel and connected to the module, wherein the data communication link communicates data outside the wheel; and a cooling fluid input port, a cooling fluid output port, and a cooling fluid circulation space within the wheel, wherein cooling fluid provided through the input port circulates through the cooling fluid circulation space and is output through the cooling fluid output port in order to cool the windings and a wall of the accommodation space during operation of the wheel; wherein the wheel has an exterior surface perpendicular to an axis of rotation of the wheel, and the cooling fluid input port and the cooling fluid output port pass through the exterior surface of the wheel; wherein the electric motor directly drives the wheel.

Description:
The invention relates to a wheel provided with electric driving means in the wheel as well as a method for coordinating the number of revolutions of at least two of such wheels attached to one vehicle.

From the literature wheels provided with electric driving means in the wheel are known. In particular wheels are known that are provided with electro motors in the wheel. Examples of such wheels can for instance be found in DE-A-2719736, DE-A-4404889, FR-A-2561593, U.S. Pat. No. 4,585,085 and WO-A-95/16300.
One of the problems occurring in the known wheels is the coordination between wheels when more than one driven wheel is used in one vehicle.

Another problem occurring in the known wheels provided with driving means is that control means are necessary. Such control means are arranged outside the wheel in a vehicle. This renders the building of an electronically driven vehicle a complex megatronic venture. WO-A-95/16300 tries to solve this by arranging a part of the control electronics within the wheel. Using several such driven wheels in one vehicle is not possible however.

It is an object of the invention to provide an electrically driven wheel of high efficiency.

An additional object of the invention is to provide a wheel that is easy to mount.

Additionally it is an object to develop a wheel that offers freedom of design of a vehicle.

Another object is a wheel that is simple to replace and to demount.

Another object is offering a wheel provided with driving means which in cooperation with other similar wheels can be deployed in one vehicle.

Said problems are at least partially solved and at least a part of the advantages is achieved by means of the wheel according to the invention.

To that end the invention relates to a wheel provided with electric driving means in the wheel, control, measuring and operating means in the wheel for operating the electric driving means and data communication means in the wheel.

Additionally the invention relates to a method for coordinating the number of revolutions of at least two wheel provided with electro motors in the wheels an further provided with control, measuring and operating means in the wheel for operating the electric driving means and with data communication means in the wheel, in which physically separated control systems control the amperage in each winding of the electro motors, the control systems in one wheel are operated by an operating system, a measuring system supplies information regarding the magnetic field strength to the control system and supplies the mutual position of the rotor and stator to the operating system, and the operating systems of the several wheels communicate one to the other by means of data communication means via a central processing unit.

Because of the wheel according to the invention a driving concept has been realised that is efficient, simple to mount and can be integrated in a vehicle.

Because of the method according to the invention it is possible to use several wheels provided with electric drive in one vehicle.

Preferably the wheel comprises a rim which coaxially at the inner side is provided with a rotor provided with permanent magnets and which rotor and rim are connected to a central shaft, and a coaxial stator provided with windings which stator is situated between the central shaft and the rotor and being connectable to a vehicle. In that way the wheel is provided with an electro motor. As a result a simple drive of the wheel is possible. Moreover no transmission is needed, particularly no reducing transmission, in which great power losses have appeared to occur.

More specifically the stator is divided into at least two groups of electrically and physically separated windings and each group comprises at least two windings each having its own control and measuring system, which control and measuring systems are situated in the wheel and the control and measuring systems are operated by an operating system which is also situated in the wheel. As a result a driving system is created that is integrated in a wheel, in which the driving system is very robust and not very sensitive to malfunctioning.

The wheel according to the invention more preferably comprises means for exchanging data with the control, measuring and operating system of other, similar wheels. As a result it is possible to couple several wheels according to the invention to one vehicle, because of which a powerful propulsion of the vehicle can be realised. In order to make the data communication less sensitive to malfunctioning, the means for exchanging data to the outside preferably are optical communication means.

In order to let either several wheels or one wheel according to the invention communicate with amongst others equipment outside of the wheel, the measuring, control and operating systems of a wheel communicate via a central processing unit outside the wheel. In this way for instance several wheels of one vehicle are able to communicate one to the other.

In order to further reduce the sensitivity to malfunctioning of a wheel even more, the control system comprises means for controlling the strength of electric current through each winding separately. In this case a winding also means a coil. When a current runs through the coil or winding this results in a magnetic field.

The control systems of the windings are connected to the operating system. Said operating system is hierarchically above the control systems and orders each control system to set and maintain a certain strength of electric current.

The wheel according to the invention is also provided with measuring systems, in which the measuring systems comprise an encoder for measuring the number of revolutions and the angular position of the rotor with respect to the stator, and a current measuring device for measuring the current through each of the windings. As a result the current through each winding can be accurately set and calibrated. Additionally the operating system is able to operate the winding well, and set the phase on each winding for an optimal working of the electric drive. Additionally the measuring system is provided with means for measuring the mechanic torque, preferably by means of strain gauges that are able to measure the strain in material accurate to the nanometre. Such means for measuring strain or torsion, deformation in metal in general, as such are known to the expert. Comparison of mechanic resulting torque and accommodated motor power give an idea of the condition of the wheel.

For a good working, the encoder preferably is connected to the operating system and the control systems are connected to the current measuring devices. As a result a modular system is created that is not very prone to malfunctioning.

The operating system is connected to a central processing unit outside the wheel by means of the data communication means. As a result the coordination with other systems in a vehicle is possible.

In order to cool the driving means in case of an all to great development of heat, the wheel is provided with cooling means, and of so desired also with active cooling means, such as fans. Additionally the wheel may be provided with means for water cooling.

In order to render cooperation of several wheels according to the invention in one vehicle possible, the operating systems in the wheel preferably are provided with a “master” setting and a “slave” setting, in which by means of the communication means the central processing unit is able to have the operating system switch from the “master” setting to the “slave” setting and vice versa. For instance when taking bends either the power demand or the speed of several wheels will vary. In order to make coordination one to the other possible, the switch from the “master” setting to the “slave” setting and vice versa is influenced by either the power demand or the speed of the wheel. It is preferred here that the wheel demanding the lowest power, i.e. the wheel having the highest speed of revolution, has been set as “master”.

In the method according to the invention it is preferred that the central processing unit has the operating system of the wheel demanding the lowest power function as “master”, and has the operating systems of the other wheel or other wheels, respectively, operate as so-called “slave”, in which each time the operating system of the wheel demanding the lowest power acts as “master” and the operating systems of the other wheels act as “slave”. As a result the driving system is easy to implement and control.

In order to anticipate future situations during driving well, it is preferred that the central processing unit includes data of the wheel struts regarding the angular position when managing the operating systems of the wheels.

The invention further relates to an assembly of at least two wheels according to the invention that are connected to a common central data processing unit by means of data communication means.

The invention further relates to a vehicle wheel having an electro motor in it, in which the electro motor is a more than 8 pole, 3 or more phased, DC synchronous motor.

Additionally the invention relates to a wheel provided with a housing mounted at a rotatable shaft, at the outside provided with a rim with tyre and at the inside provided with permanent magnets, and a housing mountable at a vehicle, rotatably connected to the shaft, provided with control, measuring and operating means and electric means for generating a magnetic field. Because of such a structure the wheel is simple to replace and can be mounted in a modular manner. Additionally a mechanic brake system is easy to mount on the shaft as an extra safety provision.

Additionally the invention relates to a wheel provided with electric driving means in the wheel, means for measuring the mechanically delivered torque, means for measuring the torque by measuring the electrically accommodated power and means for comparing the mechanically delivered torque and the measuring to the electric power. As a result it has appeared possible to establish premature wear and malfunctions in the wheel, even before an actual defect occurs. By means of the communication means a (future) defect can be established even at a distance and possibly be remedied.

Additionally the invention relates to a wheel provided with electric driving means in the wheel, provided with at least two galvanically separated motor windings, at least two galvanically separated power modules and at least two galvanically separated operating units for the power modules.

The invention moreover relates to a wheel strut provided with vehicle attachment means for attaching the wheel strut to a vehicle, and wheel attachment means for attaching a wheel to the wheel strut, in which the wheel attachment means are rotatable about the longitudinal axis with respect to the vehicle attachment means and in which the wheel strut is provided with driving means for rotating the wheel attachment means with respect to the vehicle attachment means.

As a result such a wheel strut is easy to mount on a vehicle, and the other means such a steering means for the vehicle and drive for wheels can easily be coupled.

Preferably the vehicle attachment means and the wheel attachment means are spring-mounted to each other along the longitudinal axis by means of connection means.

Preferably the connection means comprise a splined shaft which at one side is provided with a spline and on the other side is provided with driving means for rotating the splined shaft, and with a spline housing in which the splined shaft is situated and which spline housing at the bottom side is provided with accommodation means for a wheel shaft and attachment means for a wheel, and in which the vehicle attachment means are formed by a sleeve provided with means to connect the sleeve to a vehicle, in which the spline housing with splined shaft is at least partially accommodated in the sleeve, in which the spline housing and the sleeve are spring-mounted to each other by means of spring means, and the driving means are connected to the sleeve.

The structure that can be realised in this way is simple, robust, and can be integrated well in and with existing vehicles and production methods.

In order to attach a wheel the spline housing is provided with a receiving sleeve for a shaft which is positioned substantially perpendicular to the spline housing. As a result it is possible to attach a wheel stably and securely.

Additionally the wheel strut comprises spring means for buffing the vertical movement of the wheel attachment means with respect to the vehicle attachment means.

Preferably the wheel strut is provided with means for communicating with the driving means.

Preferably the wheel strut is provided with means for communication with the operating means of a wheel according to the above-mentioned first aspect of the invention. Preferably the driving means of the wheel strut communicate with the operating means of a wheel according to the invention by means of the central processing unit.

Said aspects of the invention can, if so desired, be combined. For instance a vehicle can be equipped with 2 or 4 wheel struts according to one aspect of the invention, and 4 or more wheels according to the invention. It is also possible for instance that a fork-lift truck is equipped with only one or two wheels according to the invention, but also with two wheel struts according to the invention.

As a result of a high degree of automation the wheel strut and the wheel according to the invention are particularly suitable for use in fully automatically guided vehicles. Operation can also take place by means of a joystick and so-called drive-by-wire, in which the signals of for instance a joystick or steering wheel are converted into (electric or optic) steering signals.

The invention additionally relates to a computer provided with software for the operation of one or several wheels as described, and/or for the operation of the wheel strut. Additionally the invention relates to a data carrier provided with such software.

A number of specific embodiments of the invention will be elucidated on the basis of the figures. The figures serve to illustrate the invention. The invention, however, is not limited to the specific embodiments shown.

FIG. 1 shows a wheel according to the invention.

FIG. 2 shows the wheel of FIG. 1 in cross-section.

FIG. 3 shows a cross-section of a wheel strut according to another aspect of the invention.

FIG. 4 shows a diagram of a control and operating system of a wheel according to the invention.

FIG. 5A shows a top view of a vehicle having wheels and wheel struts according to the invention.

FIG. 5B shows a top view of the vehicle of FIG. 5A.

FIG. 6 shows an alternative embodiment of the wheel according to the invention.

FIG. 1 shows the wheel **1** according to the invention. In the figure the wheel is provided with a tyre **2** , which can be used in several embodiments. The tyre may for instance be a full rubber tyre for use in low speed vehicles such as tractors, fork lift trucks or other types of vehicles for cargo transport. The wheel diameter will preferably be approximately 800 mm. The tyre may also be designed as air pressure type for use in medium speed vehicles such as for instance city taxis and medium heavy cargo transport in urban areas.

The tyre **2** is mounted on rim **3** , which is adapted to the various types of tires. A lid **4** has been mounted to the rim **3** , which connects the rim to the central shaft **5** .

At the inside of the rim **3** the rotor **6** is attached on which at the inside the permanent magnets **7** have been glued. Said permanent magnets **5** rotate along with the rim **2** . The rim **3** with the tyre **2** , the rotor **6** with the permanent magnets on it and the other parts attached to the rim, the lid **4** and the central shaft **5** are the rotating parts of the wheel.

Within the permanent magnets **7** an iron package **8** with windings **9** has been accommodated, with an air gap between the iron package **8** with the windings and the permanent magnets **7** .

The iron package **8** with the windings **9** is mounted on the central carrier member **11** and mounted on cover plate **17** by means of clamping members **10** and **13** . Said cover plate **17** has been provided with a mounting flange (not shown, preferably a B5 flange of the 250 mm type) with which the wheel **1** is mounted to a vehicle. In the clamping member **13** which is provided with an accommodation space, the control electronics **20** , amongst others consisting of IGBT's for current control and programmable logical modules for the operating system, have been accommodated. The iron package **8** , the windings **9** , the clamping members, and the electronics are fixedly attached to a vehicle by means of said flange and therefore are not a rotating part.

The central shaft **5** is provided with a hardmetal mounting bush **14** on which the bearings **23** of the wheel run. About the central shaft **5** the encoders **21** have also been mounted for measuring in what position the rotor **6** is situated with regard to the windings **9** . As a result the operating and control electronics **20** are able to control the exact phase of the voltage on each winding **9** at any moment, so that said phases are optimally adjusted to the position of the permanent magnets **7** with regard to each of the windings **9** .

In the figure lid **4** is provided with blades **15** and **15** ′. One ring of the blades **15** has been mounted directly about the central shaft, a second ring of blades **15** ′ concentrically about the first ring of blades **15** . The blades **15** ′ are open towards the most general direction of rotation (clock-wise as seen from the vehicle side) of the wheel **1** . Said blades serve to guide air into the motor for cooling. The blades **15** about the central shaft with the air inlet openings are mounted opposite to the blades **15** ′. When driving the vehicle, to which the wheel **1** has been mounted, the blades **15** will guide air into the wheel **1** , and blades **15** ′ suck air out of the wheel. As a result an air flow to the inside will be created, which flows over a cooling body on the outer clamping member **10** .

The blades function according to the principle of the centrifugal pump. The number of blades **15** about the central shaft is smaller than the number of blades **15** ′ in order to give the air expanded through heating more space and to be able to discharge it more easily.

In addition to the passive cooling by means of the blades, fans for active cooling may be present in the wheel **1** . Said fans may for instance be activated when the internal temperature exceeds a certain value.

The various internal parts of the wheel may, because of the nature of the structure according to the invention, be sealed off liquid proof in a simple manner. As a result it is possible that in addition to the passive cooling by means of blades and the active cooling by means of the fans, the inside of the wheel is cooled by means of liquid cooling. The cover plate **17** in any case seals off the operating and control electronics **20** from the outside world.

The rotor **6** can be made of aluminium and of steel, depending on the speed and bearing power needed.

The rotor **6** is carrier of the permanent magnets **7** , which ensure the torque transmission. They also ensure the guidance of the flux, which is necessary to have the magnets act as effectively as possible and thus creating a magnetic connection with the magnetic field which is generated in the stator. The stator is formed by the iron package **8** with windings **9** .

Apart from the air cooling in the motor, heat can also be discharged by means of cooling ribs **24** . In the production stage they are integrated in a casting with the cover plate **17** .

For the internal cooling of the electronics **20** a cooling body is provided. Said cooling body of course serves to cool the electronics but also has two additional functions, namely fixation of the stator and sealing off of the water cooling which can be used in larger power and higher voltages. In the figure the cooling body is still separated from the clamping member, but in series production this can become one structure part.

Clamping member **10** together with the clamping member **13** of the electronics **20** ensures that the iron package **8** of the stator gets clamped and thus cannot possibly slide in axial direction with respect to the rotor **6** . As a result the magnets **7** remain exactly in their places with respect to the rotor **6** for optimal efficiency.

The stator with windings **9** in FIG. 1 consists of 3 parts, but preferably the iron package of the stator will be made of one part. The windings **9** have been arranged around winding heads, which windings are wound according to a fixed pattern so that an optimal driving behaviour of the wheel **1** according to the invention is achieved. Electric currents run through the windings **9** , which currents generate the magnetic forces that are needed to let the rotor **6** rotate. The iron package **8** ensures an optimal guidance of the flux. A well-chosen iron package **8** guarantees a high efficiency of the wheel according to the invention.

A sealing ring ensures the separation between the internal part of the air cooling and that part where the bearing of the wheel according to the invention and the electronics is housed.

Furthermore a mounting bush **14** has been arranged as a support for the bearing (2 double-row angle contact bearings). Said mounting bush **14** has been designed in a high quality type of steel. The steel mounting bush **14** transfers the forces from the bearings on the central carrying member **11** and prevents the rolling out of the central carrying member **11** by the bearings. The bearings ensure the absorption of both the axial and radial forces and namely equally, so that during bends and irregularities in the road surface a stable rotation of the rotor **6** is obtained. Said stable rotation is very important because for an efficient working of the wheel according to the invention an air gap of approximately 2 mm at a maximum preferably is present between the rotor **6** and the stator. The bearings are after all over-dimensioned in order to ensure said air gap during a large number of operation hours (10,000 hours at a minimum).

Splines have been arranged between the stator and the central carrying member **11** so that said two members cannot possibly rotate with respect to each other.

A retaining ring is pressed by the cover plate **17** and in this way locks the bearings, which in their turn fixate the stator with respect to the shaft. In this way it is guaranteed that rotor **6** and stator remain in the same position with respect to each other.

A retaining sleeve keeps the hollow shaft encoder in its place and also ensures that the inner ring of the bearings is confined. The retaining sleeve in its turn is fixated on the central shaft **5** by a nut and screw thread.

The central carrying member **11** supports the stator and is blocked against rotation there by means of 3 spline connections which are divided over the circumference in a regular pattern. In the carrying member **11** recesses have been arranged in the surface as a result of which during mounting openings are created through which cooling liquid can be transported. Said cooling may be necessary for higher voltages than 96V and larger capacities than 12 kW.

The clamping member **13** has a number of functions.

- A: Together with clamping member **10** it clamps the central carrying member **11** and the iron package **8** , as a result of which the stator is entirely confined.
- B: It closes off the recesses that are meant to let the cooling liquid pass through.
- C: It forms an accommodation space or bowl in which the electronics are housed.

Said accommodation space in its turn is closed off by the cover plate **17** . As a result the electronics **20** are completely sealed off from the outside air, which guarantees a failure free working of the wheel according to the invention.

The ring bearing ensures additional support of the rotor **6** , so that the air gap is guaranteed at all times.

During mounting, the cover plate **17** ensures correct connection, sealing and confinement of the entire structure. This is also the attachment plate for the mounting of the wheel according to the invention to a vehicle or a chassis and preferably is provided with a norm flange B5 of the 250 mm type, as a result of which the wheel can simply be fit in the existing concepts. By means of the cooling ribs **24** extra heat is discharged during driving.

The permanent magnets **7** are manufactured in such a shape that they precisely fit into the rotor **6** . After gluing at the inside of the rim of the wheel the magnets form one unity together with the rotor. The magnets preferably are rare earth magnets. Preferably the permanent magnets have a magnetic field strength larger than approximately 1 Tesla.

The encoder for hollow shaft **21** ensures that the way covered can be measured, and also drives the electronics **20** , so that a computer or central processing unit knows in which position the rotor **6** is situated with respect to the stator. This is of utmost importance for a shock free rotation of the rotor.

The electronics and logic for operating the wheel, as well as the power electronics has been arranged within the wheel according to the invention. As a result it has become possible to achieve a number of advantages.

One of the largest problems encountered at the moment by manufacturers of electronically driven vehicles, is that all sorts of components are spread over the vehicle that later on have to be connected to each other again. As a result the manufacturing of electronic vehicles is a time-consuming activity and therefore costly as well. Additionally the production often takes place in three consecutive stages as a result of which the production time is relatively long.

FIG. 2 shows the wheel according to FIG. 1 in cross-section, as a result of which special aspects of the embodiment of a wheel according to the invention shown in FIG. 1 are further elucidated. The reference numbers here have the same meaning as in FIG. 1. In the cross-section it can clearly be seen how the rim **2** , rotor **6** , permanent magnets **7** and the central shaft **5** are connected to each other by means of lid **4** . Furthermore it can clearly be seen how the windings **9** and the iron package **8** (the stator), and the clamping members **10** , **13** with the electronics **20** are connected to the cover plate **17** . In the cross-section it can clearly be seen as a result, how the electric driving means, in this case the electro motor, are situated in the wheel **1** . By placing an electro motor in such a way it has appeared possible to achieve very high efficiency, up to 50% higher than in the usual electrically driven vehicles. In particular an electro motor as described in the FIGS. 1 and 2 results in a great advantage. For instance, the motor having permanent magnets is capable of generating electricity itself when in neutral, because the motor acts as a dynamo. Because of the mounting of the motor in the wheel it is not necessary any more either to use a transmission or a differential. The number of revolutions of the motor need not be high either.

FIG. 3 shows the wheel strut which is another aspect of the invention. The wheel stock **100** comprises a splined shaft **101** , at the one side provided with a spline **102** and at the other side provided with driving means **103** for rotating the splined shaft **101** . The driving means preferably consist of an electro motor **103** . The splined shaft **101** is rotatably situated in a spline housing **104** . At the bottom side said spline housing **104** is provided with accommodation means **105** for a wheel shaft **106** . The spline housing **104** is at least partially accommodated in a sleeve **107** provided with attachment means **108** for mounting the wheel strut **101** to a vehicle. The spline housing **104** and the sleeve **107** are spring-mounted to each other by means of a spring **109** . The housing of the electro motor **103** is connected to the sleeve **107** . The spline housing is provided with a shaft receiving sleeve **105** for a shaft which is positioned substantially perpendicular to the spline housing. The shaft receiving sleeve **105** is fixedly attached to the spline housing **104** .

The spring **109** is meant to buff the movement of the part spline shaft-sleeve with respect to the part spline housing-shaft receiving sleeve.

The sleeve **107** is provided with attachment means **108** for attaching the wheel strut **100** to a vehicle. The attachment means **108** are formed by a support **108** which is a permanent part of the structure and which is attached to the chassis or the structure with **2** conical pins and in that way forms one unity with the chassis or the structure of the vehicle.

In order to protect the spring **109** from outside influences it is enveloped by a distance sleeve **112** which at its upper side is attached to sleeve **107** . Said distance sleeve **112** consists of two parts and is provided with small air outlet openings which buff the springy action of the suspension like a shock absorber. They also serve as end stop in case the vehicle is lifted with its wheels from the ground. The lower part of the distance sleeve **115** is slid into the upper part **113** . The distance sleeve members **115** and **113** are closed off one to the other with the help of a quadring **114** .

In order to rotate a wheel electro motor **103** is activated. The rotation of the electro motor **103** is transmitted to splined shaft **101** . The rotation of the splined shaft is transmitted to spline housing **104** , as a result of which the wheel receiving sleeve attached to it rotates and a steering movement can be made. The electro motor can be provided with a transmission. The wheel strut is also provided with control and operating means for the electro motor. Additionally the wheel strut is provided with a so-called encoder which record the angular position of the wheel attachment means with respect to the vehicle attachment means. The wheel strut is also internally provided with data communication means, preferably optical data communication means. The encoder supplies operation information to the operating means of the wheel strut. The splined shaft **101** can also move up and down in the spline housing, as a result of which springing becomes possible. The vehicle attachment means can as a result move along the longitudinal axis with respect to the wheel attachment means.

The spline housing **104** is the part of the wheel suspension that rotates and moves up and down. A wheel can be attached to the spline housing **104** by means of a B5 standard flange. A brake device can be also mounted to the rear side by means of the central shaft **12** / **106** . The central shaft **12** / **106** can also be equipped with a flange on which a wheel in neutral can be attached whereas on the other side disc brakes can be mounted. When the wheel according to the invention is mounted this part can be left out.

The triangle support is a point of adhesion for a triangle. Said triangle is available on the market and makes it possible to increase the load of the spring leg from 1500 kg allowed load bearing capacity to 4000 kg allowed load bearing capacity. By using the triangle bending forces are no longer exerted on the suspension.

An extended central shaft of a wheel according to the invention is necessary for the mounting of a wheel and may also serve to mount discs of a brake system.

The spring ensures a comfortable road holding of the vehicle on which the wheel and the suspension have been mounted. In the 4 ton version with triangle the spring is indeed completely pressed in but ensures a minimal spring pressure of 1500 kg when the vehicle is positioned inclined and one of the wheels threatens to come off the ground.

The rubber O-ring ensures the buffering of the spline housing **104** in the unlikely event of the load becoming so high that the spline housing **104** bumps against the support.

Description of the Electronic Control for Operating the Synchronous Motor in the Wheel According to the Invention.

The electronic control for the wheel according to the invention is built up modularly from several elements. The several elements are hierarchically adjusted to each other. The following elements can be distinguished.

1. Power Modules

At the lowest step IGBT main current modules have been used. The structure present in said IGBT main current modules renders them highly reliable in themselves already and guarantees a low heat emission and an optimal efficiency. The main current modules control the current through the windings. The windings are divided into three groups, each having another phase. Per winding there are two main current modules. The main current modules are driven by a higher step, namely:

2. Current Regulators

At the second step **2** IGBT main current modules are connected to a current regulator and driven by the current regulator. Together with a separate current sensor working according to the Hall principle (Hall sensor) they form an independent end step that controls the current in the accompanying motor winding. In this step the module and the current regulator are already galvanically separated from the operating electronics. A current regulator having two main current modules and Hall sensor are further called 4Q-modules. The main current modules with current regulator form a control system. There is a control system per winding.

3. Vector Generator

The vector generator supplies an operating value to the so-called 4Q-modules (step **1** and **2**), which thus generate a magnetic field vector by means of windings of the synchronous motor and thus determine the moment of torque.

A so-called encoder or resolver, a measuring apparatus that very accurately measures the angle or the number of revolutions, makes the present position of the rotor with respect to the stator known to the vector generator. The quick calculation of the rotor position, which is derived from the sine/cosine signals of the resolver and the feedback value connected to it, ensures an optimal setting of the field vectors of the motor together with programmable logic modules, the so-called FPGA's.

The entire function of the vector generator, due to the combination of a micro processor and the FPGA's, can be programmed entirely over an optical fibre cable. This means that new data or changes needed for a special use can immediately be implemented (by telephone or internet) in the wheel according to the invention that is already in operation. Said changes do not only regard the software of the FPGA's, but also the hardware of the modules. It is for instance possible to change the relation in the motor itself when a winding or a module should fail so that the wheel can remain functioning. The vector generator forms the operating system. The encoder and the Hall sensors with the accompanying electronics in the described embodiment form the measuring system.

4. CPU or Central Processing Unit

The first three stages are housed together in the wheel. The CPU is situated outside the wheel and communicates with the several wheels according to the invention that may be present on a car, by means of an optical ring data bus line (ORDABUL). It is also able to carry out calculations needed for the AGV's (automatic guided vehicles) regarding the road covered, odometrics when taking bends and diagnosing the complete driving concept. Each stage guards and reports the data important for the operational situation to the CPU. An error report is immediately reported to the stage above and this one immediately reacts by taking the necessary measures, before damage may arise. The stage above is able to activate an emergency program, which reacts to the error in the correct manner. As a result an error in one module hardly influences the entire vehicle.

The modular system makes it possible to make a simple error diagnosis and to quickly locate the relevant components without having to subsequently perform complex adjusting or setting activities.

An important difference with the usual control of Asynchronous/synchronous motors is the fact that in a preferred embodiment all motor windings are divided into three groups, each preferably consisting of 30 independent windings, electrically separated from each other and each winding being driven by its own 4Q-module. Here the 4Q-modules are merely connected to each other by means of the power supply voltage, as a result of which the following advantages arise:

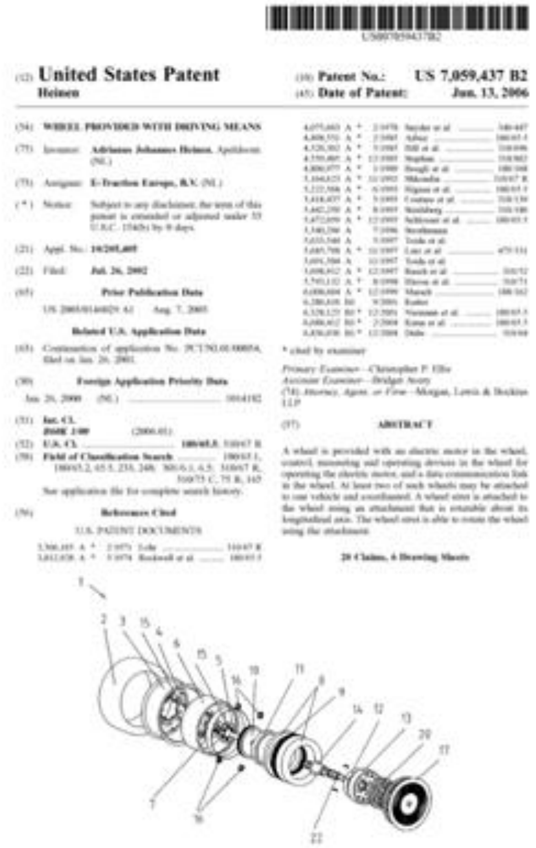
- 1: Only two phases of the normal 3-phase drive are guarded and controlled. The currents in the third phase are calculated from the behaviour of the other two phases. This means a much greater freedom in operating the electronics, and for instance in buffering the failure of one or more modules.
- 2: The current distribution can be adjusted exactly so that each motor winding generates the same field strength. As a result the actual moments of torque in each winding, generated by the field, can be adjusted and are independent from the irregularities in the electric variables of the separate windings.
- 3: The magnetic tolerances of each winding can be calibrated separately by means of the vector generator.
- 4: When a 4Q-module fails or one of the windings has short circuited, the motor can still remain operational. A fuse or relay is able to separate the defect module or phase of the other 2 4Q-modules or phases without influencing them. In this way the motor is still able to brake or, when several wheels are used, to support them. The advantages of a stage-wise structure come to the fore here in particular.

The functionality of the electronics described and their connection is further elucidated in FIG. 4. By means of a block diagram the connection is schematically shown here and the hierarchy of wheels, wheel struts and other control and operating means in an electrically driven vehicle, such as for instance a remote or automatically controlled vehicle. A central processing unit or computer **200** controls the overall exchange of data between the several parts, and ensures the possible automatic control of the vehicle. The computer **200** is connected to energy management system **300** , namely the batteries, possible generators, fuel cells or solar panels, by means of data communication lines, for instance optical data communication lines. Additionally the computer **200** is connected to a display screen **400** on which the data are presented regarding the status of the various systems. The central computer **200** is also connected to various sensors that supply information regarding the vehicle position, possible obstacles, inside climate, and the like. The central computer moreover is connected to for instance two or more wheel struts **100** according to the invention. The numbers in the figure here correspond to the parts already described.

The central computer **200** is moreover connected to at least one or more wheels **1** according to the invention. It can be seen that the wheel comprises three groups of windings **9** , **9 / 1** and **9 / 11** , control systems **32** , **32 / 1** and **32 / 11** for each group, and measuring systems **30** , **30 / 1** and **30 / 11** for each group. Additionally the wheel comprises the already described encoder **31** , which supplies data regarding the relative position of the rotor with respect of the stator to the operating system **33** superior to it. In the figure the three groups of the preferably in total at least 30 windings **9** , **9 / 1** and **9 / 11** in a wheel **1** according to the invention are shown. The windings **9** are preferably divided into three groups, each having another phase φ^1 , φ^2 and φ^3 . The current through each group of windings **9** , **9 / 1** and **9 / 11** is measured by a Hall sensor **30** . The value measured is passed on to the control system **32** . The control system **32** controls the current through a group of windings by means of 2 IGBT's. The control systems **32** are operated by an operating system **33** . Said operating system also receives data from an encoder **31** , which supplies angle information about the rotor with respect to the stator. As a result the operating system **33** is capable of choosing a good phase setting for an optimized working. The operating system **33** is coupled to a central processing unit **200** in a vehicle by means of data communication means **34** , preferably suitable for optical data communication.

FIG. 5A shows a top view of a vehicle provided with four wheels **1** according to the invention. Said wheels **1** are each attached to a wheel strut **100** according to another aspect of the invention that has also been described. Said wheel struts are each provided with means in the wheel strut as a result of which each wheel is able to rotate and in which way it is possible to drive the vehicle. The vehicle is furthermore equipped with a central processing unit **200** and batteries and control systems **300** for them. In FIG. 5B a side view of the vehicle of FIG. 5A is shown.

FIG. 6 shows an alternative embodiment of the wheel according to the invention. The reference numbers correspond as much as possible to those in FIGS. 1 and 2. The vehicle side is shown with arrow A. The wheel according to FIG. 6 is provided with for instance water cooling. The inlet and outlet, respectively, of the cooling liquid is indicated by number **30** . The inlet and outlet **30** debouch in a space **31** around the shaft through which cooling liquid circulates. In this embodiment the measuring, control and operating means have been arranged in space **32** . The electronics are arranged with the print plates oriented towards a vehicle. The cooling liquid, preferably water, mainly serves to cool the windings.


United States Patent
Heinen

(10) Patent No.: US 7,059,437 B2
(45) Date of Patent: Jun. 13, 2006

(54) WHEEL PROVIDED WITH DRIVING MEANS

(75) Inventor: Adrianus Johannes Heinen

(73) Assignee: E-Traction Europe, B.V. (NL)

(22) Filed: Jul. 26, 2002

Prior Publication Data

Related U.S. Application Data

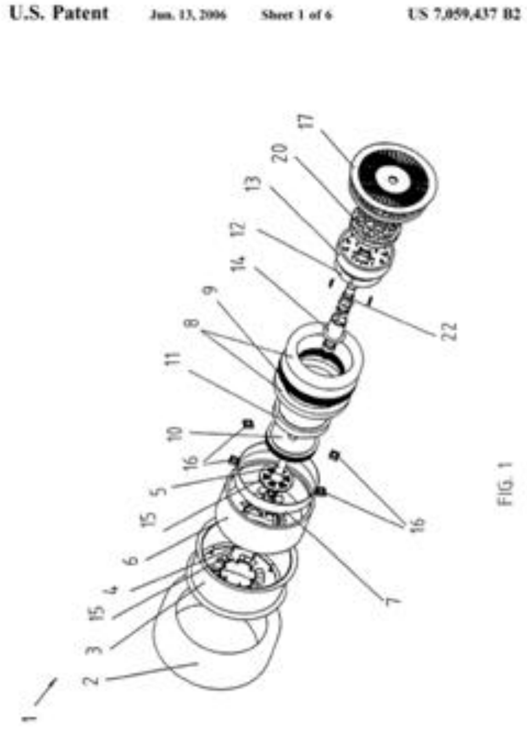
Foreign Application Priority Data

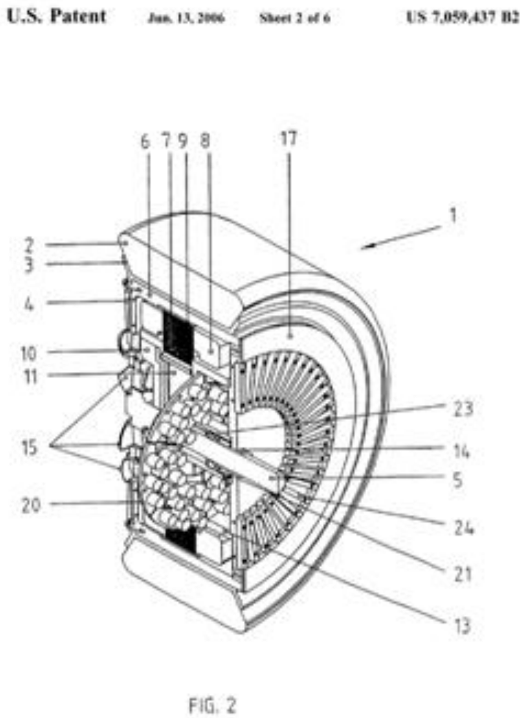
References Cited

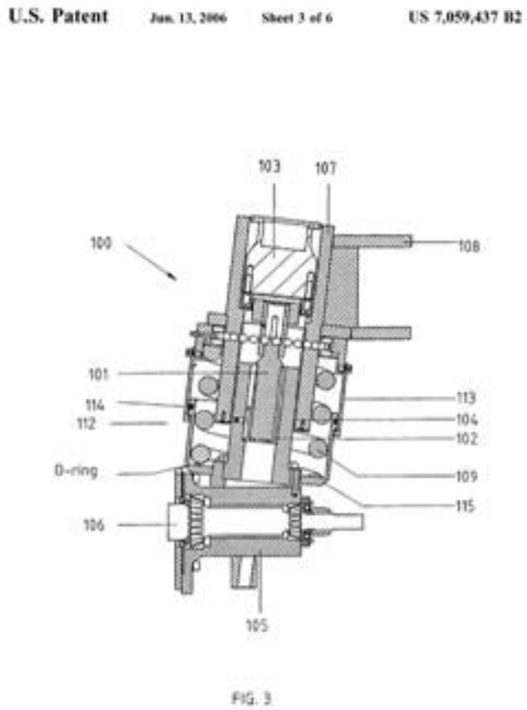
U.S. PATENT DOCUMENTS

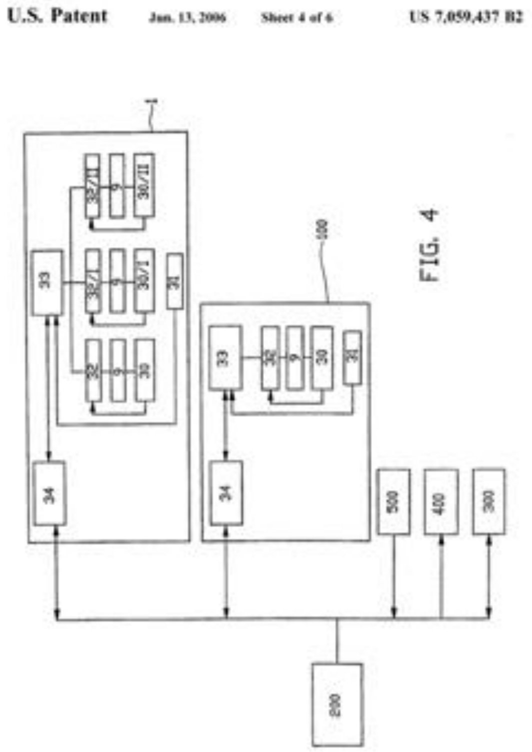
ABSTRACT

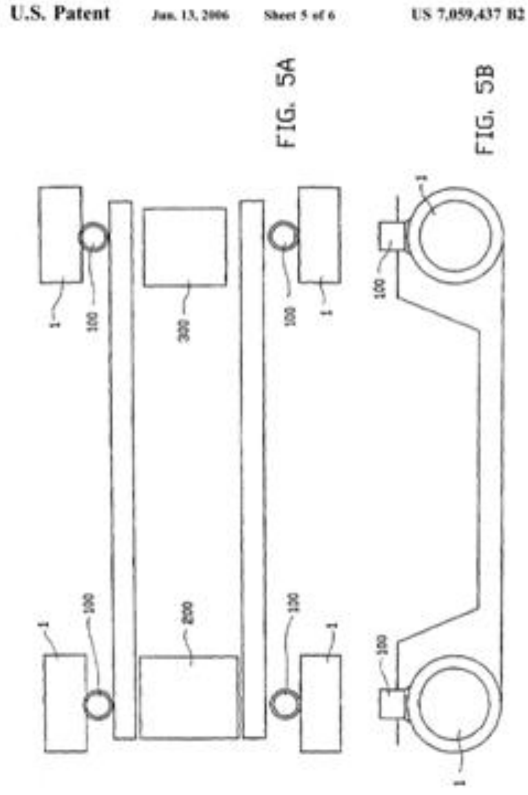
20 Claims, 6 Drawing Sheets

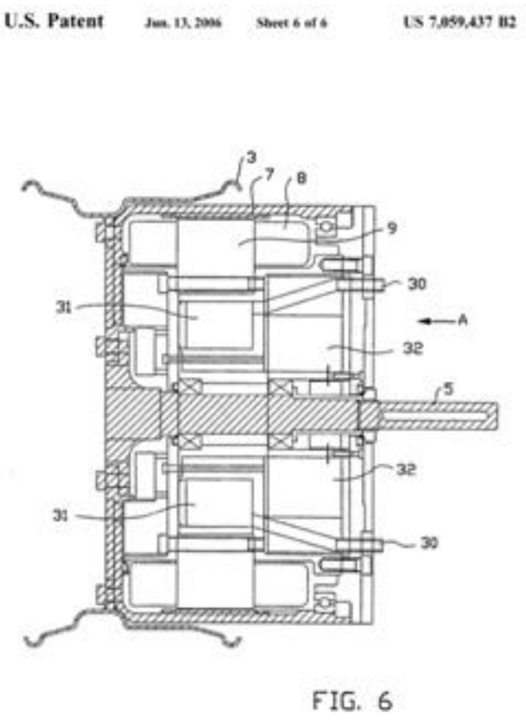













US 7,059,437 B2

1

WHEEL PROVIDED WITH DRIVING MEANS

CROSS-REFERENCE TO RELATED APPLICATIONS

2

3

4

5

6

7

8

9

10

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

* * * * *

Appendix 2: Certification fuel consumption by TNO

Delft, October 18th 2004

On Thursday October 14th 2004 we conducted measurements in Apeldoorn to establish the fuel consumption of the "e-Traction Bus". These measurements were conducted at the industrial park where the company e-Traction is located. The total distance covered was 28.3 km, divided in two sessions each covering 9 loops of more than 1.5km. The test circuit had the character of light inner city traffic in terms of speed, the number of turns and intersections. The maximum speed during the test was 40 km/h. The test is reasonably comparable to the one we conducted on May 14th 2004 in Heerenveen with a conventional VDL Berkhof Ambassador 200 and its hybrid version, "The Whisper".

During the measurements of October 14th the "e-Traction Bus" used less than 15.9 liter per 100 km (= 6.3 km per liter, or 14.8 MPG) on the test circuit. In addition, this bus uses electricity from a set of batteries, which is intended to be recharged from the power grid. The electricity used during the test is roughly 20 kWh per 100 km.

The production of CO_2 could be determined from the quantity of fuel and electricity consumed during the test. The average CO_2 production of Dutch energy companies of 0.63 kg per kWh was taken into account. This resulted in a combined emission of roughly 540 grams of CO_2 per km, of which 420 grams was production by the diesel generator and 120 grams by the energy company. For comparison: a bus that drives for instance 2.2 km per liter (= 5.2 MPG), produces 1,214 grams of CO_2 per km.

These findings are valid only in relation to the above mentioned tests. Measurements in standard cycles and in actual revenue service may reveal variances.

TNO Automotive
Delft, The Netherlands

Appendix 3: Interview protocol (Dutch)

Case studie voorbereiding,

1. Onderzoek

Hoe kan een systeeminnovatie, een product met netwerk externaliteiten, succesvol worden geïntroduceerd en geëxploiteerd worden?

2. Case study design

Semi structured interviews

3. Case info

Case:

E-Traction Europe B.V., gevestigd in Apeldoorn is gespecialiseerd in de ontwikkeling en engineering van voortuig protypen variërend van bussen tot auto's tot allerlei gespecialiseerde instrumenten met complexe elektrische componenten.

The Whisper. De meest zuinige en milieuvriendelijke bus, The Whisper, is ook in financieel opzicht een opvallend fenomeen. Minstens twee pogingen om particuliere investeerders aan te trekken liepen stuk. Dat kwam omdat bleek dat octrooien en patenten op de aandrijving van de fluisterbus, onderdelen waarmee geld kan worden verdiend, zijn ondergebracht in belastingparadijzen en dat geld daarvoor in de zakken van 'trusts' verdwijnt.

De gemeente Apeldoorn droeg ongeveer 250.000 euro bij, zo blijkt uit een staatje dat op de gemeentelijke website te vinden is. Dat geld is gestoken in een zogenaamde PPS, een Publiek Private Samenwerking, een samenwerkingsverband tussen overheid en bedrijfsleven. In totaal is door het ministerie van Verkeer en Waterstaat, de provincie en de gemeente bijna 3 miljoen euro in het project gepompt.

Aanvankelijk ontwikkelde e-Traction de Electric Corner module om prestatie tekortkomingen in de elektrische motor en versnellingsbak welke weer is toegepast in een Automically Guided Vehicle (AGV) project waar de organisatie aan werkte in opdracht van Amsterdam Airport. Hierop is deze state-of-the-art motorische oplossing gepatenteerd en later gemerkt als The Wheel. Gebasseerd op dit patent men heeft een nieuwe uitdaging opgepakt: het ontwerp van een ultra-efficiënte bus met The Wheel als aandrijf component.

Na verschillende prototypes is de ‘e-Traction Bus’ met codenaam X97 geëvolueerd in een levensvatbare technology. Onafhankelijk onderzoek door TNO Automotive liet zien dat het brandstofverbruik net onder de 15mpg ligt met minder dan de helft van de co2 emissie van overige bestaande commerciële bussen.

Stadsbussen uitgerust met The Wheel zijn nu in dienst genomen in Apeldoorn en toekomstig in Rotterdam. E-Traction is momenteel bezig met het ontwerpen van meer types van The Wheel om het brandstofverbruik van bussen, SUV’s, monorails en personenauto’s verder te ontwikkelen.

Adresgegevens:

Bezoekadres

[Adres]

Postadres

Telefoon

[Telefoonnummer]

Contactpersoon: [Voornaam] [Achternaam]

[foto]

4. Case studie vragen/onderwerpen

Interview protocol

Noteren:

- Tijdstip interview;
- Wel/geen derden aanwezig;
- Plaats van het interview;
- Naam geïnterviewde;
- Interviewnummer.

Gespreksintroductie

Goedemorgen mijn naam is Willem Cornelissen en ik studeer Bedrijfswetenschappen aan de Universiteit van Twente.

Op dit moment ben ik bezig met het afronden van mijn opleiding met als afstudeer richting innovatie en ondernemerschap. Hiervoor doe ik een afstudeeropdracht, wat ik uitvoer binnen de Universiteit. Met mijn onderzoek wil in kaart brengen hoe een systeeminnovatie succesvol te introduceren en exploiteren in de automotive industrie.

Doormiddel van dit interview hoop ik een beter inzicht te krijgen in de factoren die doorslaggevend zijn in het laten slagen of mislukken van deze innovaties.

Dit interview wordt opgenomen, zodat er voor mij geen informatie verloren gaat en zodat ik niet hoef te schrijven tijdens het interview.

Deze opname wordt alleen voor mijn onderzoek gebruikt en zal volledig anoniem zijn. Mijn onderzoek baseert zich op conclusies van alle interviews. Eventuele citaten zijn anoniem. Tevens zal ik het interview naar u toesturen zodat u de gelegenheid heeft om mij te controleren.

Het interview duurt zo rond een uur om alle zaken aan bod te kunnen laten komen. De opname zal ik gebruiken om dit interview zo correct mogelijk te verwerken daarna wordt de opname gewist.

Zijn er opmerkingen of vragen naar aanleiding van het voorafgaande?

Het interview is als volgt opgebouwd. Allereerst komen enkele vragen over de eigenschappen van uw organisatie en de introductie in het project, vervolgens enkele vragen over de samenwerking en de coördinatie van het project.

Als alles duidelijk is dan zou ik nu graag beginnen.

Introductie

De intentie van dit interview is om meer te weten te komen over hoe [partij] is betrokken bij de ontwikkeling, ondersteuning, introductie en exploitatie van de fluisterbus.

1. Zou u kort willen toelichten hoe u, als [partij], bij het project betrokken bent geraakt bij het project?

Deelname aan het project

2. Zou u kort kunnen toelichten waarom u juist voor deelname aan het project De Fluisterbus heeft gekozen?
3. Hoe zou u de rol van de [partij] binnen het project omschrijven?
4. In hoeverre zijn beslissingen of ontwikkelingen binnen andere partijen van invloed geweest op uw rol en beslissingen als gemeente?
5. Welke gevolgen heeft de deelname aan dit project voor uw organisatie gehad?
   Toelichting: wat heeft u moeten opzetten om bij te dragen aan de innovatie. Wat heeft uw afdeling organisatorisch, praktisch, etc. bijgedragen en hoe heeft uw afdeling beïnvloed.
6. Heeft u op het gebied van regelgeving wijzigingen doorgevoerd ter ondersteuning van het project?
   Toelichting: vanaf de start van het project tot en met de uiteindelijke realisatie.
7. Heeft u nog op andere wijze een bijdrage geleverd aan het project?
   Toelichting: door middel van subsidies bijvoorbeeld, of door een gegarandeerde afname van bussen.
8. Heeft u aan de participatie van het innovatieproces nog eisen gesteld, of voorwaarden waar aan voldaan moet worden?
9. Indien ja, welke voorwaarden?
10. Wat is de achterliggende gedachte achter deze voorwaarden?
11. Hoe verliep de coördinatie van het project?
    Toelichting: Was er bijvoorbeeld één leidende organisatie of een intensieve samenwerking tussen verschillende partijen.
12. Heeft u ook samengewerkt met overige [partij gerelateerd]?
13. Wat was de aard van deze samenwerking?

Toelichting: was dit bijvoorbeeld op het gebied voor het wijzigen van regelgeving.

14. Hoe zou hier in andere bestuurslagen ondersteuning aan projecten als de fluisterbus kunnen worden gegeven?

Afsluiting

15. Wat zijn volgens u de belangrijkste uitkomsten van het project, afgezien van de ecologische voordelen wat de uitvinding met zich meebrengt?
16. Is het mogelijk om u voor eventueel aanvullende vragen, telefonisch of via e-mail te benaderen?
17. Graag zou ik voor het onderzoek meer deelnemers aan het project binnen uw organisatie willen interviewen, zou u mij hiermee in contact willen brengen?
18. Heeft u zelf nog opmerkingen, suggesties of vragen?
19. Bedankt voor uw tijd en inzet.

Belscript

Goede….. mijn naam is Willem Cornelissen van de Universiteit van Twente. Ik ben op zoek naar Dhr./Mevr.

Aanwezig: Goede….. U spreekt met Willem Cornelissen van de Universiteit Twente.

(spreekt u mee) Ik neem contact met u op in het kader van de innovatie de fluisterbus, of Whisper genoemd.

Op dit moment ben ik bezig met het afronden van mijn opleiding bedrijfswetenschappen. Hiervoor doe ik een afstudeeropdracht, wat ik uitvoer binnen de Universiteit.

Met mijn onderzoek wil in kaart brengen hoe een systeeminnovatie succesvol kan worden geïntroduceerd in de automotive industrie.

Om hier meer inzicht in te krijgen voer ik een zogenaamde case study uit naar de Whisper.

Nou is mijn vraag of het mogelijk is dat ik bij u langs kom om u doormiddel van een kort interview u enkele vragen te stellen.

Ja: (datum, tijd noteren)

Nee: Dat is erg jammer mocht nog van gedacht veranderen dan kunt u mij op dit nummer bereiken , en dan wens ik u nog een fijne dag.

Niet aanwezig: Dat is jammer en wanneer kan ik Dhr/Mevr... Het beste bereiken?

(datum en tijd noteren)