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Emerald Article: The adoption of innovative asphalt equipment in road construction

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The adoption of innovative asphalt equipment in road construction

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Abstract

Purpose – The purpose of this paper is to provide insight into the adoption process of innovative asphalt equipment in road construction and how the level of knowledge as characterised by the level of education in the companies affects this process. The emphasis is on equipment used for transporting asphalt from asphalt plant to construction site or at the construction site itself. It is assumed that the uptake of this equipment is influenced by the radicality of the innovation and the company's level of education.

Design/methodology/approach – In this research, the innovation behaviour of construction companies is assessed through a case study, an expert opinion, and an industry survey (of which 55 per cent of the total population participated).

Findings – The results show that on average, experts and companies alike give more radical equipment innovations less adoption chances. Companies prefer to make minor improvements and perceive no benefits in implementing a risky radical equipment innovation. Companies that have a higher level of knowledge are found to show a more positive and professional attitude towards implementing innovative asphalt equipment.

Research limitations/implications – The defined knowledge is restricted to the formal level of education of both management and the firm in one part of the construction industry. The knowledge indicator used in this study has a high validity (it is easy to measure). Further research could focus on other types of knowledge affecting innovation adoption in other parts of the construction industry.

Originality/value – The value of this study is that it addresses the important questions of how managers of construction firms select equipment and how it is affected by the level of knowledge.

Keywords Roads, Innovation, Knowledge management

Paper type Research paper

Introduction

The purpose of this study is to provide insights into the adoption process of innovative asphalt equipment in the road construction industry and how the level of knowledge affects this process. The emphasis is on the adoption of innovative equipment used for transporting asphalt from asphalt plant to construction site or at the construction site itself. Based on previous research, it is assumed that the adoption of this equipment is influenced by the radicality of the innovation (Garcia and Calantone, 2002;

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O' Reilly and Tushman, 2004) and the company's level of education (Shane, 2000; Tabak and Barr, 1999). The outline of the paper is as follows. First, the influence of the level of knowledge on the adoption of innovations in general, the alternative types of asphalt equipment in road construction and their degrees of innovation are discussed. Second, the research methodology and empirical results are presented. Data gathering is performed through a case study, an expert opinion, and an industry survey. The paper ends with discussion and conclusions.

Asphalt equipment in road construction

In this section, the influence of the level of knowledge on the adoption of innovations in general is discussed first. Next, the alternative types of asphalt equipment in road construction and their degrees of innovation are characterised. Finally, the propositions to be explored in this study are presented.

Knowledge level

The adoption of an innovation is a very complex process that starts with a positive attitude towards new technology. According to the context of technical knowledge, collecting resources and processing information is essential in forming an opinion about any innovation and its adoption (Criscuolo *et al.*, 2010; Egbu, 2004; Maqsood *et al.*, 2007; Sexton and Barrett, 2004). From the construction literature it is clear that the capacity of a company to learn is, arguably, the most important determinant of its ability to innovate (Gann and Salter, 2000; Winch, 1998). Innovation starts with recognising opportunities (Kirzner, 1973) that originate in knowledge. When an innovation corresponds with existing knowledge and practices of the company, the company may easier recognize opportunities. Companies accumulate knowledge throughout their existence and can be seen as a reservoir of knowledge and skills. Together, with existing knowledge, new knowledge can be assimilated or created through learning (Kogut and Zander, 1992; Shane, 2000). Formal education is the primary source for this, as is knowledge acquired via experience (Root-Bernstein, 1989). In conclusion, prior knowledge is a result of relevant education (Ardichvili and Cardozo, 2000). Other research demonstrates that a higher level of formal education will most likely characterise innovative organisations and promote innovation (Shane, 2000; Tabak and Barr, 1999).

Different types of equipment

Asphalt and asphalt equipment are critical resources when executing road construction projects. A critical resource for road construction projects in terms of bulk materials is hot asphalt (Mroueh *et al.*, 2000, 2001). This product is produced at asphalt plants and transported in shipments of about 20-30 metric tons by dump trucks to the construction sites. The issues to deal with when transporting this time-critical product are traffic jams and long waiting times at construction sites when delivering asphalt.

At the site, a major component of any road construction project operates around the ground and road foundation work and the concerning machinery and equipment. Tasks include excavation, asphalting, the maintenance, repair and installation of machines and equipment and the transportation of earthmoving equipment (Mroueh *et al.*, 2000). Asphalt equipment – another critical resource – represents the highest long-term investments for road construction companies. Consequently, equipment decisions have significant impacts on the economic viability of construction companies.

Asphalt equipment such as asphalt distributors, paving machines and rollers used to spread and compact asphalt, demand high investments. On the construction site, the progress of work and prevention of interruptions in the paving process have the highest priority. Innovative monitoring techniques of the asphalt paving proves are developed, in order to prevent interruptions in the paving process and the product quality (Dorée and Miller, 2008) and to optimise construction materials logistics (Ng *et al.*, 2008, 2009; Nuntasunti and Bernold, 2006). The quality of the product decreases significantly when an asphalt spreader is at standstill. Innovative asphalt equipment may increase the reliability of the asphalt delivery process and decrease the risk of delay.

The traditional mode of transporting asphalt in this industry is by road. Two other possible transportation modes, water and rail transport, are used in other countries. Because of the high costs, the flat and open landscape in The Netherlands, air transport has not been considered in this study. However, air transportation is used in other countries for transporting construction materials. Examples are Austria where freight helicopters gain access to uphill places where no transport trucks can come and Great Britain where Zeppelins were used to transport building materials towards the inner city of London. In the framework of this study within the three modes of transporting asphalt (road, water, and rail) eight types of asphalt equipment are explored: four of them have been identified as not new, but just not applied in The Netherlands, and four of them as new and currently not applied elsewhere. Table I gives an overview of the types of asphalt equipment that are explored.

The eight selected types of asphalt equipment for this study are described below:

(1) The material transfer vehicle or shuttle buggy is a system that delivers asphalt mixtures from the hauling equipment to the paving equipment. The system consists of a truck unloading system and a storage bin with a capacity of about 25 metric tons of asphalt mixture. A system in the storage bin continuously blends and heats the asphalt mixture. A conveyor delivers the mixture to the paving spreader. Shuttle buggies are common in the US road construction industry.

(2) The mobile asphalt silo moves with the work and can be taken down and set up again in 30 minutes by one person. Its capacity is 30-75 metric tons of asphalt mixture. It does not require concrete foundations or expensive site preparation. The reliability of asphalt processing increases because asphalt is always available at the building project. The silo is filled by a conveyor. From the silo, asphalt has to be brought to the paving spreader.

Transportation mode	Existing types of asphalt equipment: Traditional for The Netherlands	Existing types of asphalt equipment: New for The Netherlands	New types of asphalt equipment
Road	0 dump trucks	1. Material transfer vehicle/ shuttle buggy	3. Asphalt open waste container
		2. Mobile asphalt silo	4. Asphalt ISO-container
Water	–	5. Bulk carrier or vessel	6. Boat and asphalt ISO-container
Rail	–	7. Bulk wagons	8. Train and asphalt ISO-container

Table I. Overview of selected types of asphalt equipment

(3) The asphalt open waste containers (mostly used for construction waste) can be deployed by conducting minor reengineering of existing techniques. Asphalt is kept at temperature for at least 24 hours by heated or insulated walls in single and two-chamber systems. After a few hours of cooling, this mode is also suitable for carrying away milling waste and has a capacity of approximately 20-30 metric tons.

(4) Asphalt in an asphalt ISO[1]-container is transported during overnight on trailers and delivered to the construction site early in the morning. This container has the same specifications as the open waste container (including the hook). However, the applied ISO norm gives the opportunity to transport it with other standardised trailers and to use other freight systems. Unfolding four legs and lowering the trailer's air suspension, enables even unloading without any heavy equipment. Just like mode two and three, certain asphalt ISO-containers include an external worm conveyor.

(5) Transport by boat using a bulk carrier or vessel can be used for big loads, up to 3,000 tonnes of asphalt. The asphalt remains warm for approximately 48 hours and is covered by only a thermal sheet. When the carrier arrives at the dock, the asphalt crust will be removed and shovel equipment needs to transfer the material into to the dump trucks for final delivery to the construction site.

(6) Transport by boat using ISO containers is an innovative way of moving fresh asphalt from the production plants to the construction sites. Because asphalt production plants are all located at wharves, transport by boat is easy when asphalt ISO-containers are used. The final transport from boat to the construction site has to be by truck.

(7) Transport by train using bulk wagons is often used to transport all kind of bulk material. Adjustments to the wagon, such as isolation and/or worm conveyor help keep the asphalt ready for use. Loading and off-loading equipment is restricted to one location, and implies a substantial investment, but generates 10,000 metric tons/hour.

(8) Transport by train using ISO containers is another innovative way of moving asphalt but has the same (and even more) drawbacks as using the water mode. Considering direct logistics costs and transport velocity, transport by train is faster but more expensive than transport by boat but still many times cheaper than transport by truck.

Degrees of innovation

There are significant differences between the different types of asphalt equipment, in terms of, risks, costs, and scale. The extent of radicality on the market as well as on the technology, on both the micro and macro levels, can be used to indicate the discontinuity of innovations (Garcia and Calantone, 2002). An innovation is defined as an idea, practice, or object that is perceived as new by an individual or unit of adoption. Adoption is a decision to make full use of an innovation as the best course of action available (Rogers, 1995). In this study, three types of innovations are recognised.

The first innovation type is called "incremental" or a continuous innovation; this concerns step-by-step minor improvements of products, processes, or services. They are adapted to the environment (Kassicieh *et al.*, 2001).

Another type of innovation is the "discontinuous" or radical innovation; this type of innovation permits entire industries and markets to emerge, transform, or disappear, providing a company with significant advantage (Walsh *et al.*, 2002; DeTienne and Koberg, 2002; Kassicieh *et al.*, 2001).

Finally, the "architectural" innovation applies technological or process advances to fundamentally change some component or elements of the business (O' Reilly and Tushman, 2004). Compared to the other two types, this innovation can be regarded as "in between incremental and radical innovation".

The extent of an innovation's radicality is applied to the different types of asphalt equipment below by relating the three innovation types to these types of equipment:

- No innovation is assigned to the traditional way of using dump trucks to transport asphalt (traditional – type 0 in Table I).
- Incremental "minor" innovation is assigned to the material transfer vehicle or shuttle buggy (type 1 in Table I). These forms of asphalt equipment improve the reliability of the paving process by adding an asphalt buffer of approximately one hour. However, this innovation does not change the asphalt process significantly. The innovation is rather easy to implement and is also able to improve the quality of the asphalt.
- Architectural "in between" innovation is assigned to the mobile asphalt silo, the asphalt open waste containers, and the asphalt ISO-container (types 2-4 in Table I). New storage units need to be designed to keep the asphalt at temperature for 24-48 hours. These types of asphalt equipment trigger bigger changes in the process, because traditional dump trucks will no longer be used.
- Radical "major" innovations are assigned to transport of asphalt by boat or train, using ISO-containers, bulk – carriers or wagons (types 5-8 in Table I). Alternatives to road transport would be very new for the Dutch road construction industry and transport companies. Successful innovation adoption demands a lot of organisational change, R&D, and financial means and cannot probably be achieved alone.

Rogers (1995) identified five characteristics, the perceived benefits, which determine successful adoption of innovations:

(1) relative advantage is the degree to which an innovation is perceived better than the idea it supersedes;
(2) perceived compatibility is the degree to which an innovation is perceived as being consistent with existing values, past experience, and the needs of potential adopters;
(3) perceived complexity is the degree to which an innovation is perceived as difficult to understand and use;
(4) perceived trialability is the degree to which an innovation may be experimented with on a limited basis; and
(5) observability is the degree to which the results of an innovation are visible to others.

Innovations that are perceived by its potential users as having a higher relative advantage, compatibility, trialability, observability and less complexity will be adopted more rapidly than other innovations (Rogers, 1995; Tornatzky and Klein, 1982). Rogers' (1995) framework adds a complimentary perspective to technology adoption in the construction industry (Fernandes *et al.*, 2006).

Propositions to be explored

Based on assigning degrees of innovation to different types of asphalt equipment, this study aims to provide insights into the adoption process of innovative asphalt equipment in road construction and how the level of knowledge affects this adoption process. Several authors have argued that the construction industry in general lags behind other industries in adopting technology (Bowden *et al.*, 2006). The construction literature also shows that formal knowledge and experience determines the ability to innovate on projects (Winch, 1998). Therefore, the first proposition to be explored in this study is the following:

P1. Choice for innovative asphalt equipment is determined by the level of knowledge in the company.

In this study, experts and managers of road construction firms are asked to express their opinion on the likeliness of adoption of the eight innovative types of asphalt equipment (plus the traditional equipment used for transporting asphalt) in the Dutch road construction industry. Specifically, the following propositions are explored:

P2. In view of the traditional nature of the road construction industry, experts will estimate the chances for adoption of innovative types of asphalt equipment on the average as low.

P3. In view of the traditional nature of the road construction industry, the adoption chances for more radical innovative types of asphalt equipment are lower than the adoption chances for a less radical type.

P4. Experts and companies do not differ in their opinion on the chances for adoption of innovative types of asphalt equipment.

Research methodology

The purpose of this study is to provide insights into the adoption process of innovative asphalt equipment used for transporting asphalt in the road construction industry and how knowledge affects this process. The insights arrive from three studies:

(1) a case study of the adoption decisions in two road construction companies;
(2) an expert opinion on the adoption of innovative asphalt equipment in the road construction industry; and
(3) a survey of the Dutch road construction industry.

Study 1 – case study

To understand more thoroughly the role of knowledge and knowledge level in companies behind the adoption of innovative types of asphalt equipment in road construction, two companies are selected – a company that choose to innovate and one that choose not to innovate. The method used for this comparison is the (short) case study. The company's level of knowledge is operationalised as the average level of formal education of the management and the entire company.

Study 2 – expert opinion

In general, innovations that are perceived by their potential users as having a higher relative advantage, compatibility, trialability, observability and less complexity will be adopted more rapidly than other innovations (Rogers, 1995). Experts are asked to express their opinion on the likelihood of adoption of the eight innovative types of asphalt equipment (plus the traditional equipment used for transporting asphalt) in the Dutch road construction industry. A forum of 14 experts who either hold key positions in asphalt production, asphalt laying or asphalt transporting companies (six persons), knowledge institutes (six experts), the national government (one expert), and a sector specialist (one expert) are given this task. They are asked to rate each of the eight types of asphalt equipment, including a weighting factor, according to adoption criteria developed by Rogers (1995).

In this study, the perceived observability (one of the five adoption criteria) is not operationalised because all types of asphalt equipment in this study are process innovations. The result of the innovation, the paved object, shows no visible variation. Subsequently, the expected variance of this characteristic is estimated nil and reflects no added value.

The results of study 2 are related to *P2*. It is expected that experts will estimate the chances for adoption of innovative types of asphalt equipment on the average as low.

Study 3 – industry survey

The research population includes all 38 asphalt producing and/or asphalt laying companies in The Netherlands. Of the total population, 95 per cent are members of the sector association VBW Asfalt. Given the small population, all companies are invited to participate in the study.

Data were collected by means of a survey among managers of companies involved in the chain of production, and use of asphalt. To determine the respondents' characteristics and the perceived innovation characteristics, a questionnaire is developed in which four dimensions of Rogers (1995) are operationalised. The survey was checked, and where necessary adjusted (mainly in terms of jargon and context) by three specialists in innovation, questionnaire design, and road construction. The four constructed scales (Table IV) were found to be reliable: perceived relative advantage: $\alpha = 0.90$, perceived compatibility: $\alpha = 0.88$, perceived complexity: $\alpha = 0.87$, and perceived trialability: $\alpha = 0.81$. The questionnaire comprises of three parts. The first examines the general company data (Table V respondent characteristics). The second part examines the respondents' opinion about the selected types of asphalt equipment. The four dimensions of Rogers are operationalised and measured on seven-point Likert scales. The last part examines the respondents' mode preference for adoption. The results of the filled questionnaires were collected and put into a data sheet for further analysis. Most of the items are ordinal scales, which have the property of being non-parametrically distributed. To make an overview of the respondents' characteristics the averages were calculated and if necessary corrected for missing values. The data were non-parametrically analysed with the Mann Whitney U-, Spearmann's Rho-, and the Friedman's test.

Because the architectural innovation consists of three concepts, assumptions were made to calculate the right average values. The results of the architectural innovation were calculated as follows. The scores from all the three types of equipment (2 to 4) of the respondents who choose these types were put into one list which contained 13 respondents in total. For the other eight respondents who did not choose types 2-4, the weighted average score of these types was calculated and put into another list. The two groups were then compared using a non-parametric, independent variable Mann Whitney *U*-test.

The survey explores the industry's opinion towards the radicality of the different types of asphalt equipment. Results of this study 3 are related to *P3*. The survey further enables comparisons to be made with the expert opinion – the results of study 2 (*P4*). Also, the role of the level of knowledge in the adoption process is analysed in this survey (*P1*).

Results

The results of the case study, the expert opinion, and the industry survey are presented in this section.

Study 1 – case study

Two companies are selected to explore the adoption process of innovative asphalt equipment and the importance of the level of knowledge on this process. The companies' names are fictional for privacy reasons. Table II provides an overview of some characteristics of the two companies.

For a contextual understanding, a comprehensive outline of the two companies is showed first. "company A" is internationally oriented and one of the biggest companies in the Dutch road construction market. "company A" consists of a number of divisions occupying in several segments of the construction industry. It owns several asphalt mills that enable "company A" to fully supply projects across the country and adjacent parts of Belgium and Germany. The road construction subsidiary employs a small team (8 fte) of engineers to innovate. From their innovations, approximately 25 per cent have sufficient potential to be implemented on a larger scale. Local government as well as reconstruction and maintenance work, account for a major share of "company A's" turnover. Its focus is on large and complex projects, to apply all in-house competencies and thereby create a significant added value. Compared to competitors, the company never quotes a price below the cost price, but fears that others overlook

Characteristic	Company A	Company B
Company structure	Subsidiary	Independent company
Company size (fte)	Large firm (> 250)	Medium-sized firm (50 > and < 250)
R&D (fte)	8	0.5
Knowledge level of the company (%)		
< & lower vocational training	50	90
Higher vocational training	20	5
University degree & >	20	5
Knowledge level of the management (%)		
< & lower vocational training	0	0
Higher vocational training	20	50
University degree & >	80	50
Type preference	(1) Shuttle buggy	(0) Traditional

Table II.
Case study: company characteristics

important aspects of the price and consequently win the tender. This approach enables management to achieve a profit percentage of 3-4 percent. Minor investments decisions can be made by the subsidiaries themselves, whereas more complex or expensive investments need to be approved by senior management at the corporate level. The other firm, "company B", is an independent small and medium-sized enterprise (SME) that focuses on local projects and on smaller jobs.

Both companies show the same percentages in net revenues, the segmentation of the nature of construction works, and the share of municipal customers in turnover. The aspects in which "company A" differs from "company B" features mainly size and level of knowledge. Subsequently, "company B's" turnover, is 13 per cent of "company A". "company B" has only 14 per cent of the total working force compared to "company A", and spends only 1/2 fte on R&D.

Considering the mode preference of the companies, "company A" prefers equipment type 1 of Table I, mainly due to the fact that it has already bought a shuttle buggy (or similar) as described above. "company B" sees no benefits in adopting any of the transportation modes. The motivation of the companies for their preference is as follows: "company A" clearly captures the benefits of all types of equipment but is also aware of their disadvantages. It recognises that some types of equipment have the weakness of too many handling movements. When implementing asphalt equipment other than type 1, further calculations are necessary to estimate their profitability. The asphalt open waste container, the asphalt iso-container, and the bulk carrier or vessel (types 3-5) could have enough potential to be implemented for the company. This is in striking contrast to "company B". This firm sees no benefits in adopting new and innovative asphalt equipment. The management of company B" feels that, in general, implementing innovations in asphalt equipment is much easier and more useful for big companies. They argue that in the road construction industry it is no use that smaller companies implement risky innovations as a first mover. They rather prefer to focus on their local markets and pay as much attention as possible to customer's wishes. The transition to the new European quality standards for raw materials (CEN) is seen by "company B" as a major threat to most SME's in the Dutch road construction industry, since bigger companies have significant advantages by using their elaborate international networks to obtain raw materials. However, "company B" does see opportunities in efficiency improvements, such as reducing office paperwork, fewer asphalt mixes, and cooperating with other companies on the condition that the product quality remains the same.

"Company A" acts much more pro-actively than "company B" in acquiring knowledge about innovative asphalt equipment. "company A" wishes to make objective analyses, to generate sustainable value with innovations and to secure its companies viability. After all, entrepreneurship inside this company is stimulated. Second, investigating alternative types of asphalt equipment emphasizes much more the innovation attitude of "company A". Efficiency improvements as "company B" proposes hardly adds value to the product (in contrast to innovations) and ends up with increasing price competition. Dealing with innovation has a much lower priority. Subsequently, risk avoiding strategies of "company B" have proven to be sustainable. The average level of knowledge in the company and among the management on types of asphalt equipment is substantial higher in "company A". This knowledge affects investment decisions on innovative types of asphalt equipment.

Study 2 – expert opinion
The expert opinion on the adoption potential of the eight transportation modes is rated on a ten-points scale. A weighted score is determined according to adoption criteria developed by Rogers (Table III).

In the next step the scores of the experts are translated into a score between 0 and 1. The traditional technology (dump trucks) is given the score 0.50 on all dimensions (Table IV). Since the expert opinion is a result of a group process, no statistical analysis on this data is possible. Nevertheless, some observations can be made:

- The most likely types of asphalt equipment to be implemented are type 3 the asphalt open waste container, and type 1 the material transfer vehicle or shuttle buggy.
- The incremental innovation (type 1) is given the highest adoption score (0.53) above the traditional type 0.
- The architectural innovations (types 2-4) are given on average a lower adoption score (0.48) than the traditional type 0.
- The radical innovation (types 5-8[2]) score on average 0.42, below the traditional type 0.
- Aggregating the expert opinion towards equipment types "new for The Netherlands" (0.45) and "new" (0.47) both are given a lower average score than the traditional type 0.

These observations support the second proposition. Only three of the eight innovative types of asphalt equipment score above the traditional type and three types (2, 7, and 8) score 1 standard deviation below the average score of the innovative types. Finally, the average score of the innovative types (0.46) is below the score of the traditional mode.

Result study 3 – industry survey
In total, 21 of the 38 companies responded to the invitation which gave a response rate of 55 per cent. Table V gives an overview of the characteristics of the participants in this study.

Striking in the results is that none of the radical types of asphalt equipment (types 5 and 6) is preferred for adoption, and that the likelihood of the incremental innovation (type 1) receives a higher average score ($\Sigma = 0.55$) (Table IV) than the architectural innovations (types 2-4) ($\Sigma_{average=}$ 0.48). The lower average score of the architectural innovations is explained by the low score on perceived compatibility.

Table III.
Expert's operationalisation and weighting factors of the perceived benefits

Perceived benefit	Operationalisation	Weighting factor
Perceived relative advantage	Costs	10
	Capacity	8
	Flexibility	8
	Reliability	9
Perceived compatibility	Velocity	7
Perceived complexity	Standardization	7
	Legal aspects	7
Perceived trialability	Feasibility	8

Table IV. Comparison of the perceived benefits projected on the different types of asphalt equipment

	Stage 1: expert opinion					Stage 3: industry survey					
	Perceived relative advantage	Perceived compatibility	Perceived complexity	Perceived trialability	Σ	Perceived relative advantage	Perceived compatibility	Perceived complexity	Perceived	Σ	Number
Traditional	0.50	0.50	0.50	0.50	0.50	–	–	–	–	–	4
Type 1	0.57	0.50	0.45	0.50	0.53	0.40 (0.72**)	0.25 (0.45*)	0.53 (0.70)	0.65 (0.58)	0.55 (0.82**)	4
Type 2	0.45	0.30	0.29	0.40	0.40	0.35 (0.48**)	0.18 (0.23*)	0.47 (0.55)	0.63 (0.58)	0.48 (0.58)	6
Type 3	0.61	0.40	0.50	0.40	0.54	0.28 (0.52*)	0.20 (0.43*)	0.52 (0.83)	0.55 (0.25)	0.45 (0.69*)	3
Type 4	0.58	0.40	0.45	0.40	0.51	0.32 (0.55*)	0.23 (0.43)	0.48 (0.68)	0.60 (0.60)	0.47 (0.72*)	4
Type 5	0.56	0.30	0.45	0.40	0.49	0.17	0.13	0.27	0.67	0.30	0
Type 6	0.57	0.30	0.45	0.30	0.48	0.12	0.12	0.15	0.60	0.23	0
Type 7	0.37	0.30	0.45	0.30	0.37						
Type 8	0.34	0.30	0.45	0.30	0.35						

Notes: Significant at: $^{*}p < 0.05$; $^{**}p < 0.01$, at (MWU – two tailed); Value in Parentheres are the difference between preferred and not preferred (not shown)

Characteristic	Average
Age of company (years) min. (2) max. (105)	66
Company size (fte)	194
White-collar employees (fte)	33
Part-time white-collar employees (fte)	4
Blue-collar employees (fte)	138
Part-time blue-collar employees (fte)	19
R&D (fte) 20 per cent of resp. spend no fte on R&D	3.0
Knowledge level of companies(%)	
$<$& lower vocational training	60
Higher vocational training	24
University degree & $>$	16
Knowledge level of managements(%)	
$<$& lower vocational training	0
Higher vocational training	24
University degree & $>$	76

Table V. Respondent characteristics

The Friedman's test gives proof that the mean ranks differ significantly ($\chi^2 = 15.325$; $df = 2; p \ll 0.00$). In general, the industry prefers an incremental innovation above an architectural innovation, and additionally an architectural above a radical ($0.55 > 0.48 > 0.27$), this confirms *P3*. Further, from the data it appears (Table IV) that there is significant difference between the total score of the preferred types for innovation and the total score of the not preferred types of asphalt equipment, except type 2 (0.58). Especially, the relative advantage of the preferred types 1-4 is perceived significantly higher. Consequently, the companies expect that adoption of the preferred innovations can give them an edge over other companies. Results on the general preference of the respondents for the different types of asphalt equipment show (Table VI) that 81 per cent of road construction companies prefer innovation over no innovation.

Comparing the results of the companies with those of the experts some conclusions can be drawn. The expert opinion and the average scores of the companies do not significantly differ. This paraphrases that the expert opinion and the scores of the

Innovation types	Preference of respondents (%)	Number of respondents
No innovation	19	4
Type 0	–	–
Incremental innovation	19	4
Type 1	–	–
Architectural innovation	62	13
Type 2	29	6
Type 3	14	3
Type 4	19	4
Radical innovation	0	0
Type 5	–	–
Type 6	–	–
Total		21

Table VI. Preference of innovation types companies are less than 1 standard deviation apart. Further, the expert opinion does not differ significantly (difference is less than 1 standard deviation) from the preferred types of asphalt equipment for innovation. Summarising, *P4* was confirmed: experts and companies do not differ in their opinion on the chances for adoption of innovative types of asphalt equipment.

The level of knowledge in the company (Table VII) is not correlated with the overall score on the perceived benefits. However, there is a significant correlation between the level of knowledge in the company and the (perceived) complexity of the innovation ($r = 0.52$; $p = 0.03$; two tailed). Further, there is a negative correlation between knowledge level in the company and the perceived advantages of the not preferred innovation ($r = -0.48$; $p = 0.03$; two tailed). These findings support partially *P1*.

Discussion and conclusions

This study provides insights into the adoption process of new and innovative equipment used for transporting asphalt from asphalt plant to construction site or at the construction site itself and how the level of knowledge affects this process. The data indicates that the Dutch road construction industry is rather conservative when it concerns adopting innovative types of asphalt equipment. In the expert opinion only three of the eight innovative types of asphalt equipment score above the traditional type in terms of perceived benefits. The forum of experts, express the most likely to be implemented innovation is an incremental innovation; a small step. These observations support *P2*.

This is partially confirmed by the companies in this sample, 19 per cent of the companies preferred not to innovate; another 19 per cent prefer an incremental innovation. However, most companies that do want to innovate prefer an architectural innovation (62 per cent), meaning they are willing to take a bolder step than the experts, but are reluctant to choose the radical innovation. The perceived benefits of the innovation characteristics for an incremental innovation are higher valued than the perceived benefits for an architectural or radical innovation. This is explained by the relative low scores on the perceived compatibility of architectural and radical innovations. Given the existing technology, organisation and regulation of asphalt production and transport, it is more difficult to realise the benefits of these innovations compared to an incremental innovation. Still, the architectural innovation of mobile asphalt silos is the most preferred one.

Non-parametric correlation coefficient (r)	Level of knowledge	Perceived relative advantage ($\alpha = 0.90$)	Perceived compatibility ($\alpha = 0.88$)	Perceived complexity ($\alpha = 0.87$)	Perceived trialability ($\alpha = 0.81$)	$\Sigma\alpha = 0.91$
Preferred innovation ($n = 17$)	Firm	0.10	0.37	0.52*	−0.49	0.31
	Management	−0.18	−0.22	0.22	0.01	−0.18
Non preferred innovation ($n = 21$)	Firm	−0.48*	−0.35	0.23	−0.06	−0.24
	Management	−0.21	−0.09	0.22	0.21	−0.06

Note: Significant at: $^{*}p < 0.05$ (MWU – two tailed)

Table VII. Spearman's Rho correlation matrix for the level of knowledge of the (non-) preferred innovation characteristics and the perceived benefits

The total perceived benefits of the two radical innovation concepts are clearly valued lower by the respondents than the incremental or architectural innovation. No respondent saw an opportunity to adopt the radical concepts within their firm. The Dutch road construction industry finds to which extent the innovation improves the efficiency and reliability of the process most important. So, support is found for *P3*: the adoption chances for more radical innovative types of asphalt equipment are lower than the adoption chances for a less radical type. The results of this industry study, however, seem to indicate willingness: 81 per cent of the companies surveyed indicate that they are interested in innovation by indicating a preferred type of asphalt equipment. On the average there is no significant difference between the companies and the experts. This means that *P4* is confirmed: experts and companies do not differ in their opinion on the chances for adoption of innovative types of asphalt equipment.

The level of knowledge affects the perceived benefits in two ways: companies with more knowledge have a preference for innovations that are more complex. Further, it appears that construction companies with more knowledge are better aware of the disadvantages of the types of asphalt equipment they are not interested in. These findings support partially *P1*: choice for innovative asphalt equipment is determined by the level of knowledge in the company. This finding confirms the argument that is often made in the construction literature that the construction industry becomes more innovative when levels of knowledge and the influx of highly educated employees increase (Bernold, 2005; Bossink, 2004; Gann and Salter, 2000). This finding is also in line with the conclusion of Cohen and Levinthal (1990) that technology adoption is affected by the degree to which an innovation is related to a pre-existing knowledge base within a firm. The adoption of innovations depends on a firm's ability to identify and exploit knowledge from the environment (Cohen and Levinthal, 1989).

Although interesting conclusions can be drawn from this research, it also has its limitations. Regarding the high response rate of 55 per cent of the total population, the absolute number of responses remains quite small. Further, the defined knowledge is restricted to the formal level of education of both management and the firm. This indicator has a high validity; it is easy to measure. However, the level of formal education fails to indicate the role that (relevant) experience might play. This research puts a basis by measuring innovation perceptions and preferences; however future research is needed to map the entire adoption process. From a construction industry point of view it would be interesting to know if the above conclusions are applicable for the whole industry.

Adoption of innovative asphalt equipment results in an innovative approach to the production and transport of asphalt and other building materials. One implication is that firms are improving their logistical organisation of the road construction process. The progress of work and prevention of interruptions in the paving process on the construction site improve by implementing innovative asphalt equipment.

Notes

1. ISO stands for the International Organization for Standardization. This organization is administered by accreditation and certification bodies. ISO maintains a family of standards for quality management systems.
2. Regarding transportation modes 7 and 8: after discussion with the experts and evaluation of the scores it has been decided not to include them further. In general, "rail" in The Netherlands is not a realistic option because of the overuse of the railway net.

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