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THE DESIGN OF ROADS AS A CRAFT: THE ROLE OF RESEARCH, EXPERIMENTS AND EXPERIENCES IN ROAD CONSTRUCTION 1880-1960

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Abstract

The building of roads has never been based merely on exact sciences. From the very beginning, experiments and evidence-based knowledge have been of utmost importance.

This paper deals with the new challenges that the building of roads faced from motor vehicles starting around 1900. Firstly, the rubber tyres from motor vehicles were hazardous for the unpaved, macadam roads. The road builders had to solve these construction problems before the roads literally disappeared in a sand storm.

With the new technology of motor vehicles, drivers were handling 60-80 horsepower, as compared with one or two; the heavy vehicles became a new challenge for the road constructors. A single vehicle could completely damage a road in minutes. Strong prohibitions to protect the roads had to be made until construction solutions were developed.

In the beginning of this period, road construction was mostly an evidence-based business, but with the new challenges there had to be new kinds of solutions. National and international cooperation was soon established and the diffusion of technical knowledge was spread systematically. The developments of new methods were made systematically: locally with small experiences and nationally with larger experiments. Among the larger, a Danish experiment from 1924-1937 will be mentioned in this paper, as well as a important large American experiments in the 1950s (AASHO 1950, WASHO 1953-54 and AASHO 1958-1960).

Engineers and construction work has always been based on scientific knowledge. However, for many years, theoretical issues were mostly merely background knowledge for the people in the practical world and pure theory was only for a few secluded researchers. This picture changed slowly but steadily.

The Second World War was a very important event for the development of road construction. The construction of the large landing strips for the steadily growing airplane industry was an especially important driving force in this period. After the war, this knowledge came into action and new actors appeared in the construction business when the large bitumen companies became important. The most important of this became Shell with its publishing of books with recommended matrix tables for thickness and formulas for the different sets of traffic loads.

> This company not only delivered asphalt but they owned and conducted an increasing number of companies which made the bitumen roads. Because of this, there developed a new knowledge infrastructure where knowledge moved in the closed world of the international companies in contradiction to the until then open knowledge transfer in the public sector.
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> Around the 1960s, the principles for road construction were, in many ways, followed for many subsequent years. The challenges with building roads were, to a large extent, solved and the infrastructure for the design of roads was made.
>
> However, the design of roads still had a large element of craft.

THE PRINCIPLES OF ROAD DESIGN

When a road is designed, there are a lot of decisions to be made about its technical construction. These decisions have, to a large extent, been based on evidence. The responsible persons—or person for a large part of history—should decide what kind of materials to be used for the construction, how much of it there should be in each of the layers of the road, how to handle it, how wide the road should be, the shape of the bends, ditches and draining, and many more things. Moreover, there was not just one formula for construction. There could be a basic concept but every piece of road had to be specially constructed according to the composition of the different layers of materials of the underground, the actual contour of the landscape, the existing water-bearing stratum, the local available building materials and many more elements. Of the more uncertain elements was the future use of the road: what kind of vehicles should drive on it, how fast, with what weight and how many vehicles will drive on the road during its lifetime. When motorised cars began to drive on the roads, this future use was rather uncertain. Along with this came considerations over the roadside trees, milestones and future maintenance.

Concerning railroad construction, a large part of the preparation could be made through a theoretical basis. Since the beginning of the 1800s, knowledge of railroad construction has grown. Bridges could be planned through the use of formulas. This knowledge had been known world-wide back in history and refined through experiments and theories from technical high schools.

The road engineers had their education from technical high schools, too, (or military high schools) and had nearly the same kind of background as the railway engineers. However, their work was, to a large extent, isolated around the country and without much help from the theorists at the technical high schools. Moreover, the development of road traffic since the beginning of the 1900s has been almost a revolution compared to the more stable development of the railways.

This study will focus on the building of highways and not on local roads. It is by the building of highways that the most developed knowledge has been used. It is based on examples from Denmark, which is a European industrialised country and in many ways representative for this type of society. As will be explained, the role of the county road surveyors and other road engineers has been much the same in other European countries.

THE ROLE OF THE COUNTY ROAD ENGINEER IN THE 1800S

In the 1800s, Denmark's highways were built and maintained under the superintendence of the county road engineer. After the railways became the highest prioritised transport system, all of the roads came under the field of responsibility of the county councils. In Denmark, this transfer was made in 1868.

The system of organisation was very weak in all counties. The county road engineer was employed and had some roadmen to assist him with the daily maintenance. The county roads were from 100 to 700 km long. A typical county district covered roads 320 km long. Each roadman had around 6½ km to keep. They had a lot of piles of broken stones along their roads and when a wheel track became too deep, they could fill it with stones. Besides those many roadmen, the county road engineer had approximately three assistants to help him with the daily contacts to those approximately 50 roadmen. This was the extent of the organisation. The road engineer did not even have a personal secretary to help him with administration duties such as correspondence, accounts or making appointments.

With this dense organisation, the county road engineer had a rather dense budget. From this, he could hire some stone breakers—often on a piece-contract for a year—and some haulage contractors. The raw materials were often taken or bought from the neighbourhood.

The road engineer was the only person with knowledge on how to make roads. His only legitimate help could come from the Chief Highway Surveyor in Copenhagen, who supervised all of the roads in Denmark. His support was rather sparse, as well. He had only one personal aide at his side.

All of the knowledge at that time was based on evidence. Even all of the road engineers at the end of the 1800s were educated at the technological university or at the Military High School. The theoretical side of road building was reduced to almost nothing. A regular education at Polyteknisk Læreanstalt (the Technical University of Denmark) started first in 1859 with a few courses. And the connection between the university and the practitioners was very weak.

The development was slow and was based on small-scale experiments made by the road engineers.

One important new technique came from Scotland where John McAdam has lent his name-macadam. In reality, the technique had further development through his successor James Patterson. Instead of the traditional technique of building a road with an excavation of a road bed and a foundation of large stones, the new technique used rather thin layers of broken stones with each layer rolled solidly and with a throughout draining. The layers should be around 20 cm thick.

This technique was used in Denmark from the middle of the 1800s. As in most road building, only small parts could be renovated each year because of the economy. Around 2 % of the roads were rebuilt by this method each year. Surrounding Danish and other European roads, stone breakers could be seen, becoming visible evidences of this new technique.

INNOVATIONS IN THE 1890S – THE STEAM ROLLER AND PAVEMENT

The spreading of new techniques was rather slow in the 1800s. The active players in the field were few and the infrastructure for information very slight. The following story tells the situation in the 1890s with two of the most important new innovations in road building—the steam roller and pavement.

The central person in this portion of Danish history was the county road surveyor of Copenhagen, W. R. Winkel. He was responsible for some of the most important roads in Denmark that carried the traffic to and from the capital.

In the end of the 1880s, Winkel heard about a new method to build roads that could handle heavy traffic. In Germany in 1885, F. Gravenhorst invented a new kind of paving stone, “kleinpflaster” (small paving stones). Instead of using large stones, Gravenhorst found that small stones cut in a little camber shape could make a solid cover laid in a little sand over a macadam bottom. When the process was refined, the standard became around 10 cm high stones with a base from 7x7 to 10x10 cm and laid in very regular curves over the width of the roadway.

The steam roller provided a useful tool for this process. By this technique, many more km of road could be rolled than with the ordinary horse-driven roller. Horses were satisfactory for small rollers but for large ones, the many horses made it difficult to handle the roller because, for example, approximately 10 horses needed to be unbelted and re-belted when the roller rolled back.

The steam roller was not a new invention. In 1860, a French roller was already in action, and in 1867, the English factory Aveling and Porter in Manchester extended their business for traction and plough engines with this new tool. This was a wise decision; the factory became the leading factory for steam rollers in the world until the last steam roller left the factory in 1930.

But for the Danes, the steam roller was new, and Winkel wanted to look further on the promising tool in connection with the new method for pavement. He had to go to Germany, but the travel was rather expensive and his budget too small. He had to have funds. Thanks to the Chief Highway Surveyor, he got money for the study tour.

When he came home, he gave a very enthusiastic report on what he had seen in Germany. The pavement could handle very heavy carriages and the steam roller could be used not only to pave with stone but on the macadam made roads, as well. He then asked the Chief Highway Surveyor to provide money for an experiment with both of the new techniques, but his petition was in vain. The argument against him was that with all those advantages, the local counties should pay for their experiments themselves and not the state; it could only be a success.

But the local authorities didn’t pay. In Copenhagen, Winkel asked for money each year but without results; the time passed by. In 1898, he made some experiments on a road and real pavement in full scale was implemented in 1901. At that time, the innovation process took 15 years.

It went a little bit better with the introduction of the steam roller. Thanks to the urging from Winkel, a private businessman became aware of the new tool and bought two rollers, which he received around 1894. Those rollers were rented for road building and showed that the technique was useful. Winkel finally received his steam roller around 1906, more than 20 years after it had proven its usefulness in neighbouring Germany. Thanks to the private enterprise, the technique was introduced while the more cautious public sector decided to wait.

The development in the sector progressed slowly. There came only a few small technological improvements with the horse-driven carriage in those days. The most important improvements were the iron axle and the use of springs. Together they gave a lower weight and a more stable driving; therefore, the speed and/or the weight of the cargo could be expanded slightly. While the speed could not be increased very much, the cargo could be expanded but seldom to more than four tons. The development did not give a radical change and besides, the demand for transportation in the growing industrialization could be handled through the known techniques.

THE FIRST THREAD FROM MOTOR CARS: SPEED

The slow speed for invention and introduction of innovation didn't last. When the motor cars appeared in a cloud of dust, they became a visible challenge for the road managers. The problem was not only evident in Denmark but in all countries where the new vehicle was seen.

While previous vehicles could be pulled by a few horses and the speed and load were kept within limits, the new motor car had no limits. The motor's , soon had a power of 20 HP or more.

In short, there were two aspects surrounding the new technique: the vehicle could drive at a very high speed and it could carry a much heavier load. Speed was the worst problem in this time where most drivers were rich people who used cars for leisure.

Cars had to have rubber tyres in order to drive fast. The vehicle would have been rattled to pieces if it not had had a stable suspension system.

For the roads, this became dangerous. The macadamised roads were covered by sand to hold the broken stones together but the fast wheels sucked the sand up. When the sandstorm had died down after a car had passed, the broken stones were naked and vulnerable to damage.

Road managers all around the world had the same problems at the same time. Only pavement with stones could resist the new vehicle and it was unrealistic to use this method on more than the few most trafficked roads.

No one knew what to do. No experts at technological universities could give the answer. The practicians had to find out themselves.

In the beginning of the new century, the road engineers realised that a more dense cooperation was necessary. They began to meet together and to make organisations. The most important of these organisations was the Permanent International Association of Road Congresses (PIARC), where people from all over the world met in Paris in October 1908 to discuss the new challenges. More than 107 papers were presented by representatives from 33 countries. The logo for the conference was very symbolic. On each membership card for the more than 1600 participants, there was a picture of a roadman working in the forefront and in the back a horse carriage was driving out of the picture while a motorised car approached.[1]

In Denmark, the road engineers from all of the counties wanted to meet, as well. Isolated they had been trying to solve the same problems. The interchange of information would be the first step to better roads. They had their first meeting in 1894; they hardly knew each other. In spite of a fine meeting over three days, there went more than 10 years before the next meeting in 1905.

In 1911, the problems were too massive and the need for a more continuous exchange of information had to be organized. Therefore, the 24 county engineers, together with the Chief Highway Surveyor, made an organisation for the exchange of information. From that point on, the engineers met once a year.

The solution to the problem with the sand was simple. Instead of spraying water on the road in dry periods the surface was covered by a thin layer of tar to bind the sand. This method was not new. It had been in use in France in 1867 and in Denmark from the 1880s. But those first uses were to prevent the dust in the towns. The spreading was simple because it involved pouring the tar on the road and subsequently wiping it out with brooms. The engineers responsible for the highways had to use the technique in a more efficient manner, which involved using machines. The first of an automatic tar spreading machine was used in Denmark around 1915.

It is interesting to note that this organisation was an organisation for only a few and very exclusive members. It had its very narrow aim to communicate technological knowledge. Therefore, Denmark didn't have a broader, politically oriented organisation like the Swedish "Svenska Vägföreningen," which was created in 1914 and was inspired from the American "Good Roads Movement."

NEW TECHNOLOGY AND HOW TO JUDGE IT – A GENERAL VIEW

The construction of roads has much in common with the construction of many other products. There is not merely one solution and it is not possible through science to predict the right one. This characteristic is the same for the construction of roads, a washing machine or space rocket.

A closer look at this kind of technique will show four different criteria for well-made technology: *It shall serve its purpose*. This is obvious but not always that easy to judge. It is possible to look at the finished product and test it to see how it can fulfil its purpose. For instance, can a fast car drive on this new road? Function alone is not enough. Functional items must have a level of quality (and to give an absolute definition of quality is almost impossible); therefore, a more subjective judgment had to be made. It could be disadvantages like a tar covered road that gives the vehicles black spots on the bright guards. From here there are no borders to the aesthetic quality, where the subjective impression is the only objective.

The next criterion is: *Can this solution be realised through a reasonable economy?* This has always been a high priority criterion. The economy is formed by different components. For a road, there are raw materials, which should be rather inexpensive; much of it can be obtained at nearly no cost through free through local resources. Another component is the cost of labour. For the building of roads, there had to be enough free labour in the time of the year where it is most convenient to tar the roads—there could be competition with the harvesting period which could claim the free labour force.

The last two criteria are more difficult to handle. They are about how the technology will function in the future. Here it is not possible to test a solution for its future use. There can only be guesses made about the future. Technology can only be built on experiences either after tests or after the more subjective feelings based on personal experiences from the engineer.

The first of those criteria is: *Will this solution be a long-term technical success?* The actual test made for the new construction is not enough; what the success will bring tomorrow has to be considered. Especially for roads, this is an important factor. As the above mentioned county road surveyor Winkel explained: a road is influenced by vehicles in the same way like when a man is drinking brandy. You can't see on him when he had got one or two glasses, but when he had got 20, it is possible to see. In the same way, roads became destroyed through internal friction of the broken stones. The problem was that nobody knew how or why.

The last criterion is: *Will this solution be an economical success?* As compared with the former very uncertain prediction of the future, there is a rather more uncertain prediction. For instance, the roads made of concrete could be sufficient and economical when they are constructed. They will be sufficient in the long term, too, but with some necessary repairs—and those repairs would be very expensive.

TO MEASURE THE TEAR ON THE ROAD

The engineers knew that many vehicles could tear a road into pieces as illustrated by the story about brandy told by Winkel. The road authorities and politicians did indeed not know how much the vehicles wore the roads. One very heavy truck could go through the surface of a road, but many lighter trucks had to drive on a road for, perhaps,, half a year before the road was demolished. This final accumulated wear and tear was the big question for the road authorities. It was the most important question when the authorities met, but they did not get any single answer. Road construction was no exact science, and the fundamental research developed slowly at first.

A kind of rule-of-thumb was developed about the tearing from vehicles when the road authorities calculated how long a special road construction could exist before repairing or what kind of coating was the best for a road with a certain or calculated traffic. It could be stipulated through extrapolation with the help of a traffic census.

A popular formula for the tear on the roads became *tons per meter per day*. A representative sample of vehicles was weighted, and from this an average was found. The numbers of tons could now be stipulated by counting the numbers of vehicles of every kind. This fluctuated only a little over time in the 1920s, where, for instance, the weight of a horse carriage in 1929 was 2,39 tons, an automobile with pneumatic tyres (a personal car, vans, and light trucks) was 1,55 tons, while a motorcar with a solid or a half-solid tyre had a weight of 5,78 tons (trucks).

Please note that the broadness of the road was included in the formula. The tear would be different on a road depending on whether the traffic was spread over a broad range or all the vehicles drove on the same track.

The counting could, by this theory, be used to plan road building. After inspiration from Sweden, the rising numbers of vehicles in the future could ultimately be doubled. So, the most trafficked roads—those with at least 200 vehicles on a day, equal with 75 tons per meter of the road—should be extended. For example, in 1925, a traffic count performed in Århus, the second largest town in Denmark, showed that the road with the most traffic had a total transportation of 2.300 tons in eight hours.

The formula was rather unscientific, and later on, it proved to be completely incorrect. In spite of the fact that it was used to make serious decisions about, for instance, dimensioning, the engineers on the road knew that the formula was wrong. They knew that a heavy truck or a bus weighing eight tons tore the road much more than eight passenger cars weighing one ton each. This is an example of the common sense that ruled at that time.

THE START OF A SYSTEMATIC COLLECTING OF KNOWLEDGE

From the experiments on a smaller scale, the engineers soon made larger experiments. The practitioners were still the promoters.

An epochal experiment was establishing a so-called pilot road at Roskildevej, the most trafficked road out of Copenhagen. The originator of the project was county road surveyor Winkel in Copenhagen. The large highway was a distance of only 250 meters made particularly broad so there could be a lane for each kind of traffic: horse driven vehicles had a lane, motor cars with massive or half-massive tyres had another, and cars with pneumatic tyres had the last lane. Now it was only a matter of counting the numbers of the vehicles in each lane (it soon became possible to make the counting automatic by electronic devices). Therefore, it was now possible to measure the tearing from each kind of vehicle.

Each lane was built by all kinds of construction. By this experiment, it was possible to see how each of them was affected by a certain type of traffic.

The experimental road was established in 1926, and information was collected until it was closed down in 1939. Both before and after, there have been traffic censuses recording how many vehicles—and thus how much weight—a road has been loaded with over a period. In contrast, experiments like the one in which the traffic was divided cost enormous sums. The Danish experiment was actually a rather brilliant solution to have results with so few monetary resources.

In defiance of efforts were made to obtain information about the traffic the interpretation of the collected information could give very wrong results. This was the case in 1939, when a report from the Committee of Roads at the Danish Road Laboratory stated that trucks did not tear as much on the roads as twice the traffic from a private car. Even though a truck at that time only had a total weight of 3.6 tons, the result was—with the knowledge of today—very far from reality.

SCIENTISTS CAME INTO THE ACTION GRADUALLY

For many years, the employees at the Technical University had played a rather small role in the development and discussion of new road construction. This situation changed gradually from the middle of the 1920s. Still, the practically minded engineers were the centrifugal force. In 1921, they took an initiative to a committee under the association of engineers. The committee itself had 14 members, among them the Chief Highway Surveyor. It also had a long row of subcommittees that worked with new techniques and materials.

An important institution was formed in 1928. It was the Danish Road Laboratory that had its tiny start. One of the reasons behind the laboratory was the more extensive use of chemicals in building roads. For instance, should the tar be analysed for its content of different substances in the effort to find the right balance between its different fractions? Soon, a kind of standard was established for this and later for many other chemicals.

The laboratory was, during its beginning years, only a “defensive” and not an “offensive” actor in the sense that it controlled chemicals more than it developed and experimented with chemicals. Even then, the accumulated knowledge could be used for more future-oriented tasks. Therefore, the laboratory had for some years a tight connection with the Technical University and in those years it made experiments with wear and tear on road surfaces. In the end, the laboratory was more a laboratory for the practitioners than it was a research laboratory and it regained its organisational connection to the practising engineers.

A central man for this was the professor at the Technical University, A.R. Christensen. He was the only professor in road building from 1917 – 1949 and became the leader of the aforementioned laboratory.

Professor Christensen initiated the Dansk Vejtidsskrift (Danish Road Journal) in 1924 and was the responsible editor until 1950, when his successor as professor took over this post, as well.

The journal was very important for the Danish road sector. Through this journal, all road builders in Denmark could be informed in Danish (many didn't understand English in those days) on not only experiences from Denmark but from abroad, as well, and translated articles or impressions from study tours. For many years, the journal was published by the county road engineers' organisation but the knowledge was also useful for many small municipalities with their own road administration.

For the interwar period, the picture was the same; road building was still dominated by experiments and experiences by the road engineers. The few researchers helped to explain why some solutions were good and others were bad.

NEW PLAYERS ON THE ROAD

For many years, the county road surveyors were almost—together with the local politicians—completely responsible for the roads. They became very powerful because the money flew to the sector after some heavy taxes on cars and later when petrol was introduced after the 1920s. The local road authorities had office buildings, garages, a fleet of machinery and many workers for both construction and repair.

Their powerful position changed dramatically through time where many other players came "on the road." This meant that there not only were technical solutions for road building but a lot of new shareholders with agendas which the surveyors had to take into account.

For instance, there arose new problems after the first problems were solved. When the problem with the dust was solved through the use of tar, the cars could then drive faster. But the roads were not built for fast vehicles; therefore a lot of accidents happened.

Already, the police could make local speed limits and were active in resolving accidents. The many people injured or killed in these accidents forced the politicians to reform the field and in 1932, the police became a strong and active partner through the revised Road Traffic Act. Whereas traffic signs before were made and erected uncoordinated—often by private motor organisations—they became a responsibility for the police. From then on, all new roads were to be planned through a process where the police became equal with the road engineers.

Once again, the planning of new roads or the straightening of old curved ones needed to be made through experiences. The police used statistics on accidents when planning new roads.

While the increase in power held by the county road surveyors in one way gave them more possibilities to make larger and better roads, their power was administered under a lot of new regulations and rules. For instance, at a railway level crossing there needed to be a sight distance area, no private way outs at highways and building lines for new houses. Many of these rules were made after consultations with the road surveyors. For instance, a large collection of rules was published in 1942 with recommendations for widths, angles, speed and so on. This first collection of rules was only 37 pages. Later on, the rules expanded greatly. For instance, in 1979, the register over the people behind the rules was printed on 145 pages. Some years later, all the rules took more than a running metre in a bookcase.

Besides those many rules, the economical means also came to the road authorities through a growing complex web of rules.

Still, contrary to the many rules, the local surveyors for many years had their freedom to decide themselves about how the construction of the road itself had to be.

EXPERIMENTS WITH CONCRETE ROADS

The Danish engineers heard about roads abroad that were being built with concrete. Many of the stories sounded good. Information came from the US and the UK about successful implementations. The experiments had to be made in Denmark, too, to see whether this technique was suited to the Danish climate.

The first small pieces of roads were established in 1919. The experiments went well except that this kind of road was not suited to horse-driven vehicles. Still, the experiments went on partly supported by the strong Danish cement works.

The construction of concrete roads was rather complicated. There needed to be a lot of heavy machinery for mixing and laying and stamping out the concrete (the last with an imported American machine). After the building of the road, the concrete had to harden for many weeks.

This complicated building process was probably the reason that the process was not implemented in many places. Denmark’s smaller counties were too little to make experiments on that scale. No Danish firms received the necessary knowledge or machinery for this type of road. Therefore, companies from Sweden helped with the building of roads. At least in the interwar period, the use of local companies was preferred for all public work.

Therefore it was necessary to obtain the experiences of other countries. Not at least the Italian autostradas and German autobahns were much discussed in those years.

The first of those roads was built only with plates on a thickness of 10-15 cm. Later on, they became 12-25 cm thick. To prevent the plates from breaking, there had to be regular notches.

The roads were more expensive than the other solutions of that time. In addition, the engineers had doubts about the long term quality because not many roads of this type were built (the quality of the German roads showed later on to be of a bad quality; where the roads originally were 90 % build by concrete only 27 % were in concrete 50-60 years later).

Later, in the 1950s, there were new concrete roads made on a larger scale, but those roads didn’t became long term successes, either.

THE ASPHALT ROADS

Asphalt became the new super material. (However, the first asphalt road were laid in Copenhagen around 1840 on the sidewalk to the road for the richest people in the capital.) A real road covered by asphalt had been in Paris since 1858 and a similar road came in Copenhagen in 1890. Its main advantage was its lack of noise when the horse carriages drove on it.

The use of asphalt was rather limited. It made a comeback in Copenhagen in 1923 after a new method was copied from London. Still, it was for a little piece of road in the big city. Using asphalt for long highways was inconceivable at that time.

The technology was very complicated while the asphalt had to be spread at high temperatures up to 200° Celsius. The necessary techniques were in the hands of private companies that delivered asphalt to make, for instance, floors at private companies.

Asphalt was used in those emulsions that were popular in the 1920s and 1930s, but with a new technique in which expensive machinery could be avoided and the laying of a certain type of carpets had its birth in 1929. This technique came from Germany where Karl Dammann had invented a mixture of asphalt with fine corned materials that could be rolled out cold by hand under primitive conditions. There were established factories in Denmark to make this material, and in the end of the 1930s, many kilometres of road received a surface of this kind.

After the Second World War, the asphalt began its triumphal progress all over Denmark. This time, it was the warm asphalt and when the asphalt mix could only be warm after a 100 km drive, there were a lot of small asphalt works built around the country. The most economic laying of asphalt was with the help of laying machines. Because of the many small local communities—more than 1000 in those days—private enterprise took over this part of the former 100 % public sector. Only one county had its own asphalt factory and laying machinery.

This development meant that the knowledge about the technique was split between the private and public sector.

EFFECTS OF THE SECOND WORLD WAR

When Dwight D. Eisenhower became the US president, he evoked The Interstate System, which had been started back in the late 1930s. He had seen the military advantages of the German autobahns and wanted the program to be accelerated. Therefore, funding for the construction of the project was accelerated and the name was changed to the National System of Interstate and Defence Highways.

Construction standards for the Interstate System were already established in 1950. The first large experiment with controlled traffic in full scale was carried out. It was called “Road Test I-MD” and was made by a cooperation of road administrations, the American Association of State Highway Officials (AASHO). A vehicle with two axles and one with three axles drove on an existing concrete surface over a long period of time. From this experiment, a very clear understanding was gained: that a vehicle would tear much less if the weight were divided on more axles.

In 1953-1954, another consortium of road administrations, the Western Association of State Highway Officials (WASHO), extended the experiment with the same results.

The most extensive experiment—and thereby the most important—was again made by AASHO. Over a period of two years (1958-1960) vehicles were running almost 19 hours a day with 10 different combinations of vehicles six to seven days a week. All in all, there were six test roads each with many different kinds of surfaces and with small bridges.

The aim was to find the relationship between the numbers of loads with a known weight and the combination of axels on different covers and thickness of the bases.

The result was that a double axel could not carry double the weight of a single axel but rather only 1.8 times. An enlargement of the weight of a truck from 8 to 10 tons shortened the lifetime of a road's surface by 58 %.

SCIENTIFIC THEORIES ABOUT ROADS

Parallel with this experiment, theories were developed in other areas of road technology. Here, only a few will be mentioned.

Measuring the capacity of the underground to consolidate a given road surface proved to be important. In California, the so-called CBR-method (California Bearing Ratio) was developed, which, in principle, said that with a larger sinking of a piece of earth under a vertical influence, the lesser was the bearing ratio. The results were published by the California State Highways Department in 1928, but the theory was first used after 1942 to a greater extent. Hereafter, it was the number one method for many years.

During the Second World War, the belligerent countries lacked a method for dimensioning roads for heavy traffic, especially for fortification of airfields for the heavier bombers. Therefore, many results appeared after the war for civil use. In 1943, Donald M. Burmister published a method for two and three layer covers on a circular area. This method was extended by Hank in 1948. According to this, the influence became an unvarying effect on a circular area. Hank published some tables with his results. This kind of table was important in this business, while the users from a few parameters—for instance, the stipulated coming traffic—could read the recommended thickness of the different covers.

The importance of road foundation durability also began to be an important question. Therefore, the categorisation of the soil according to its type began. The method from R.R. Proctor concerning the control of the compression of soil from 1933 came into use during the war and was in use for a long time.

Those and other theoretical and practical studies resulted in some practical tools, causing the American Asphalt Institute to publish the book *Thickness Design* with curves over traffic and its weight compared to the CBR-number of the base. This material was built on the assumption that the roads had to be dimensioned to a rising traffic of 80 % over 20 years.

The other widely-used resource was a publication from Shell (a large producer of asphalt), "Shell 1963 design chart for flexible pavements." Here the CBR-number was similarly determined and the total number of axels counted in equivalent 10-tons axels calculated over the concerned road's lifetime—here it was only seen on the heavy traffic—neither the personal vehicles nor the vans had any measurable influence on the lifespan of a road.

This target for the traffic pavement, “the accumulated times heavy axel passages,” became rather important. The theory was developed in the 1960s and was used by the road authorities through the publication from Shell. The reason, according the theory, was that every time a heavy axel passed through a piece of road, the pavement was influenced, and this finally resulted in a stress fracture like the way a wire is broken by a certain number of bends. A road had, therefore, to be dimensioned at least as strongly so that it could bear the total weight in its lifetime.

The equivalent 10-ton axels, Æ10, became a measure for N, the number of 10-tons axle load that was compared to the actual accumulated. The actual weight on an axle can be inserted into a formula, and it is possible to calculate the influence. The damage of the pavement is changed with the fourth square root of the axle load. For example, if we had to compare a truck with an axle load of six tons related to a rear axle of 0.6 tons, the truck has the same destructive power as that of 10,000 passenger cars; accordingly, a truck of 12 tons’ weight has the effect of 160,000 passenger cars!

Since the 1960s, a continuous evolution has occurred. Among these new methods, the EDP has given new possibilities for calculating relationships between many different factors; however, the principal understanding of the pavement was shaped and resulted in a drastic improvement in road building.

A RIGHT FOUNDATION FOR THE ROAD

The next great progress in the development of the theories happened late in the 1950s, when much more attention was given to the condition of the soil. New methods for geological investigations meant that the ground for the roads was taken into consideration. Together with the aforementioned new scientific theories, better construction could be performed. For instance, at road construction, the engineers started to stabilise the soil in different ways with rolling and vibrating tools and after adding concrete or hydraulic lime.

The tools for road building have had a similar evolution. The mechanisation happened seriously after the Second World War, and an almost industrial building of roads happened since the 1960s. This was often parallel with a reorganisation where allocations of contracts and liberalisation gave better possibilities of organising the road building (and, for instance, the maintenance, also) more rationale.

In the last years of the millennium, more asphalt mixes were developed. Where several layers were already being used in the 1960s, in the 1970s asphalt came in depths down to 37 cm or more. This was not only a better way of road building through the materials but a better way of calculating the building, too. The weight limits for the vehicles were raised, and a more extensive load was allowed. While the foundation layers were getting better, the heavy trucks gave a larger tear that resulted in wheel tracks. Especially when the maximum-allowed tyre pressure was raised so super single tyres could be used, serious problems appeared. Once more, it was necessary to develop new technologies for making softer bitumen so the surface layer could be flexible and straight after hard influence from a heavy vehicle.

DISCUSSION AND CONCLUSION

The development of road building had been nearly revolutionary since the first motorised cars drove on roads. Until 1960, the development in rough outline was:

- New and more complicated techniques replaced each other (tar was replaced by solution, which was replaced by concrete, which was replaced by asphalt, which was replaced by asphalt in depth)
- New players came into the arena (for instance, the police)
- Stronger central control/steering through the use of money
- Increased use of scientific/experimental-based knowledge
- Knowledge and experiences grew gradually at commercial actors

The road engineers experienced many consequences from this development. Firstly, the organisation of the work couldn't be handled by a few people anymore. There had to be a more specialised organisation behind the work where the responsible road engineer had to have a lot of specialists behind him to cover all the necessary knowledge. This gave some organisational changes. For instance, since 1949, the responsibility for the highways in Denmark has gradually transferred from the local authorities to the central state institution Vejdirektoratet (Directorate for Roads).

Another important consequence was that the large companies surrounding the road building industry accumulated their own knowledge that they kept as their own trade secret. For instance, the large petrol companies (fronted by Shell) took over the delivery of asphalt as the (waste) product from their refineries. They also gained control of the firms that lay out the asphalt. They made world wide internal networks with this knowledge that the public road sector had to buy along with the products.

The knowledge was spread and came into action almost immediately. The way from the experiments and the research institutions became short in time. Seventy years before, it was difficult obtaining money to travel from Denmark to Germany and now the travelling to conferences, buying books and journals have become routine.

Even with the rising research activity around the world, the experienced-based knowledge was still important. A very unreliable estimate built on my knowledge could be that the decisions made about the construction of roads around 1960 was based on 10 % theory, 20 % experiments and 70 % experiences—this last part still kept a flavour of craft in the road building business.

CV for Jørgen Burchardt

The paper is based on research made for the Danish Road and Bridge Museum about the history of the highway in Denmark from 1868 to 2006. From this research, Jørgen Burchardt and Mette Schønberg published: “Lige ud ad landevejen. Med hestevogn og bil på amternes veje 1868-2006”. 2006 383 p. (Transl.: On the highway. With horsepower and cars on the county roads, 1868-2006).

Burchardt is a senior researcher working for museums, universities, government institutions and private companies. He is educated as an engineer and a social anthropologist and has further training in industrial heritage and in the diffusion of scientific knowledge.

[1] Weingroff, Richard F.: „...From dense ignorance and otherwise" A (not entirely serious) look at America's 100 (plus) years war with Europe. Manuscript from Federal Highway Administration.