同济大学综合交通信息与控制工程系
Department of Transportation Information and Control Engineering
TONGJI UNIVERSITY

NATIONAL EXPERIENCE AND INITIATIVES UNDERTAKEN TO SUPPORT SUSTAINABLE AND GREEN ROADWAY INFRASTRUCTURE IN CHINA

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UNITED NATIONS ESCAP
Economic and Social Commission for Asia and the Pacific

Islamabad and virtual event
6 December 2022

Outlines

- Introduction
- Road Construction and Standards
- Technical Features of Road Design and Construction in China
- Representative Road Projects
- Developmental Trend of Construction Techniques
- Summary

Introduction

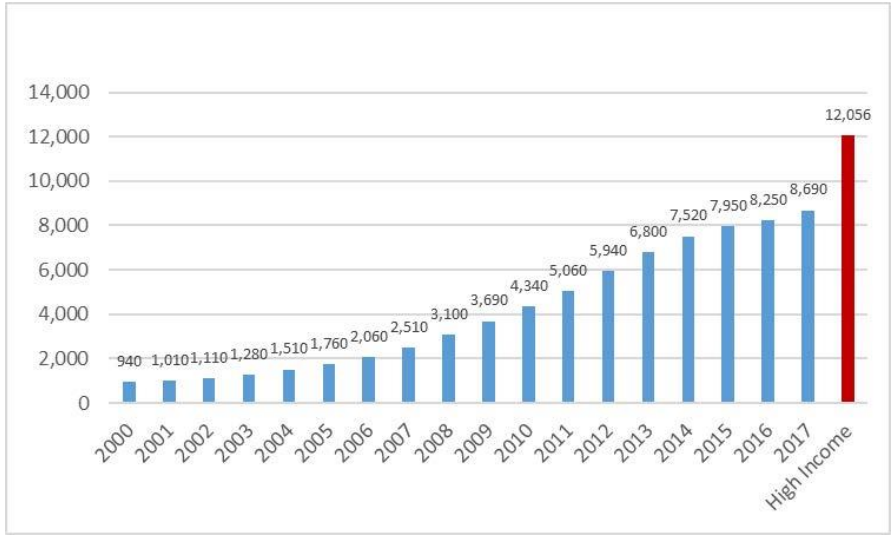
1.1 Background

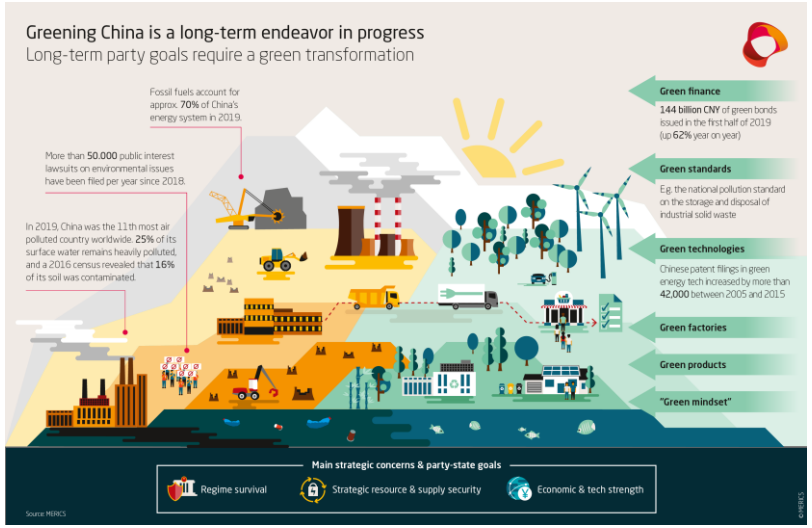
China's socioeconomic conditions and trends

- China is a growing influence on its developing economies through trade, investment, and is transitioning to a more green and resilient growth model, aiming at promoting a lower-carbon energy path:

- **Stable growth socioeconomic development**
  - Since China began to reform its economy in 1978, GDP growth has averaged over 9 percent a year, and more than 800 million people have lifted themselves out of poverty. There have also been significant improvements in access to health, education, and other services over the same period.
- **Latent risks under the socioeconomic prosperity**
  - China's high growth based on investment, low-cost manufacturing and exports has largely reached its limits and has led to economic, social, and environmental imbalances.
- **Urgent requirement for green and resilient economy**
  - China's socioeconomic development is currently in the transition to a low-carbon and resilient economy structure.
  - The shifts in resources and technologies are needed.

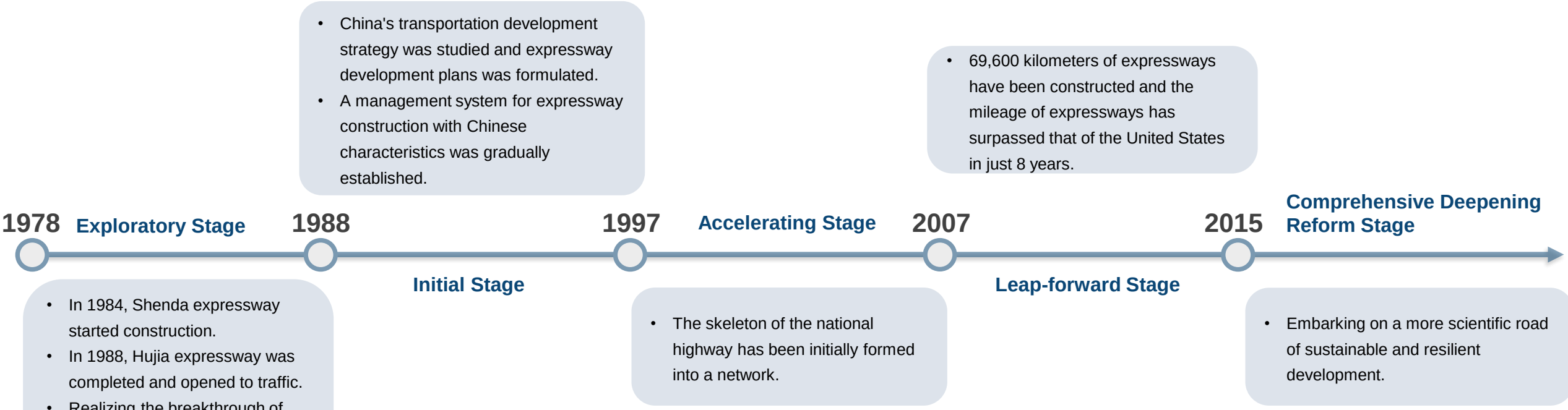
Fig1. World Bank Measurements of China's Per Capita GNI: 2000-2017(by US $)



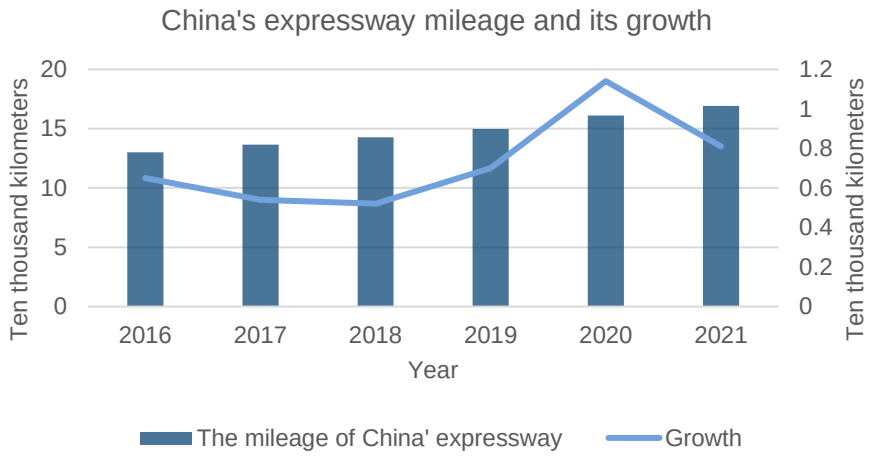


1.2 Development of China’s Expressway

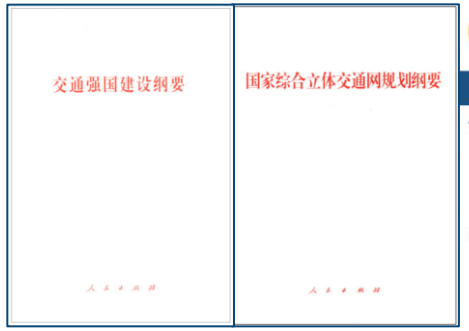
- Since the opening of the first expressway in mainland China in 1988, the expressway has achieved leapfrog development.
- At the end of 2019, the total mileage of national expressways was 5 million kilometers and the mileage of China's expressways reached 161 thousand kilometers, forming a huge high-speed transportation backbone network. China attaches great importance to the construction of smart expressways.
- Looking back on the development of China's expressways over the past 30 years, it can be roughly divided into five development stages:



1.3 Expressway in China



- Total mileage of China’ expressway: 169100 kilometers, ranking first in the world.
- Coverage: 98.8% of the urban population of more than 200,000 cities and prefecture level administrative centers, 88% of the county-level administrative regions and about 95% of the population in China.
- Increasing trend: 95% of the expressway network construction tasks of 2035 have been completed. The pace of national highway construction will slow down significantly in the future.



The goals and strategic plans of China’ expressway:

- Optimizing some routes and avoiding ecological protection areas and environmentally sensitive areas
- Expanding the coverage of expressway
- Strengthening the channel capacity between urban agglomerations and key cities
- Strengthening the channel capacity within the urban agglomeration and improving the efficiency and resilience of the road network

The expressway in China will be **Cost-effective, Green, Low-carbon, Intelligent,** and **Resilient**.

1.4 Policies in Sustainable Infrastructure

Intelligent:
applicable & user-friendly

Cost-effective:
more effective & less expenditures

Resilience:
flexible in various conditions

Green:
ecological & environmental -friendly

"Thirteenth Five-Year Plan for Transportation Technology"

- Elaborated the contents of future intelligent infrastructures, especially on the construction of scenario-based and application-oriented highways

"Guiding Opinions on Promoting the Construction of New Infrastructure in the Field of Transportation"

- Further clarified that the construction of new infrastructure in the field of transportation must achieve cost-benefit standards by 2035

"Outline for the Construction of Nation with a Strong Transportation System"

- Described a set of principles, key actions, and guidelines to create national scale net resilience gain and improve the continuity of critical services

"Fourteenth Five-Year Plan for Construction of New Infrastructure"

- Proposed innovative concepts are proposed such as ecological co-construction, standard support, and entire life cycle

The future infrastructure needed in China is going to be **Intelligent, Cost-effective, Resilience** and **Green**.

Road Construction Standards

2.1 Architecture of Standards

Road Construction Standards

Laws and Regulation

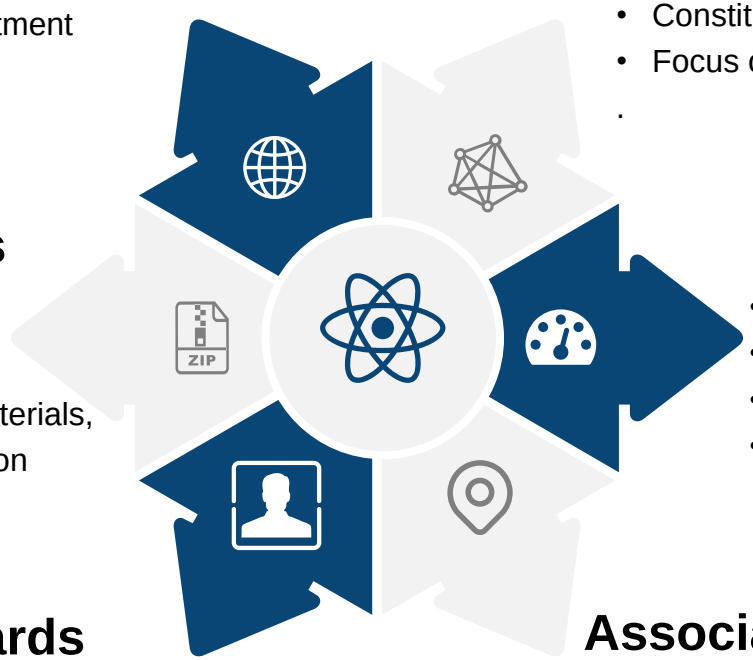
- Mandatory rules
- Published by Judicial department or Ministry of Transport

Ministerial standards

- Mandatory standards
- Basis of standards system
- Regulate most of the common materials, design parameters and construction techniques

Enterprise standards

- Constituted by enterprises for products or techniques
- Improve their competitiveness in market
- Various and detailed



National standards

- Mandatory standards
- Constituted by Standardization Administration
- Focus on key problems in road construction

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Local standards

- Constituted by local government
- Take effect in specific regions
- Supplement to mandatory standards
- More practical and advanced

Association standards

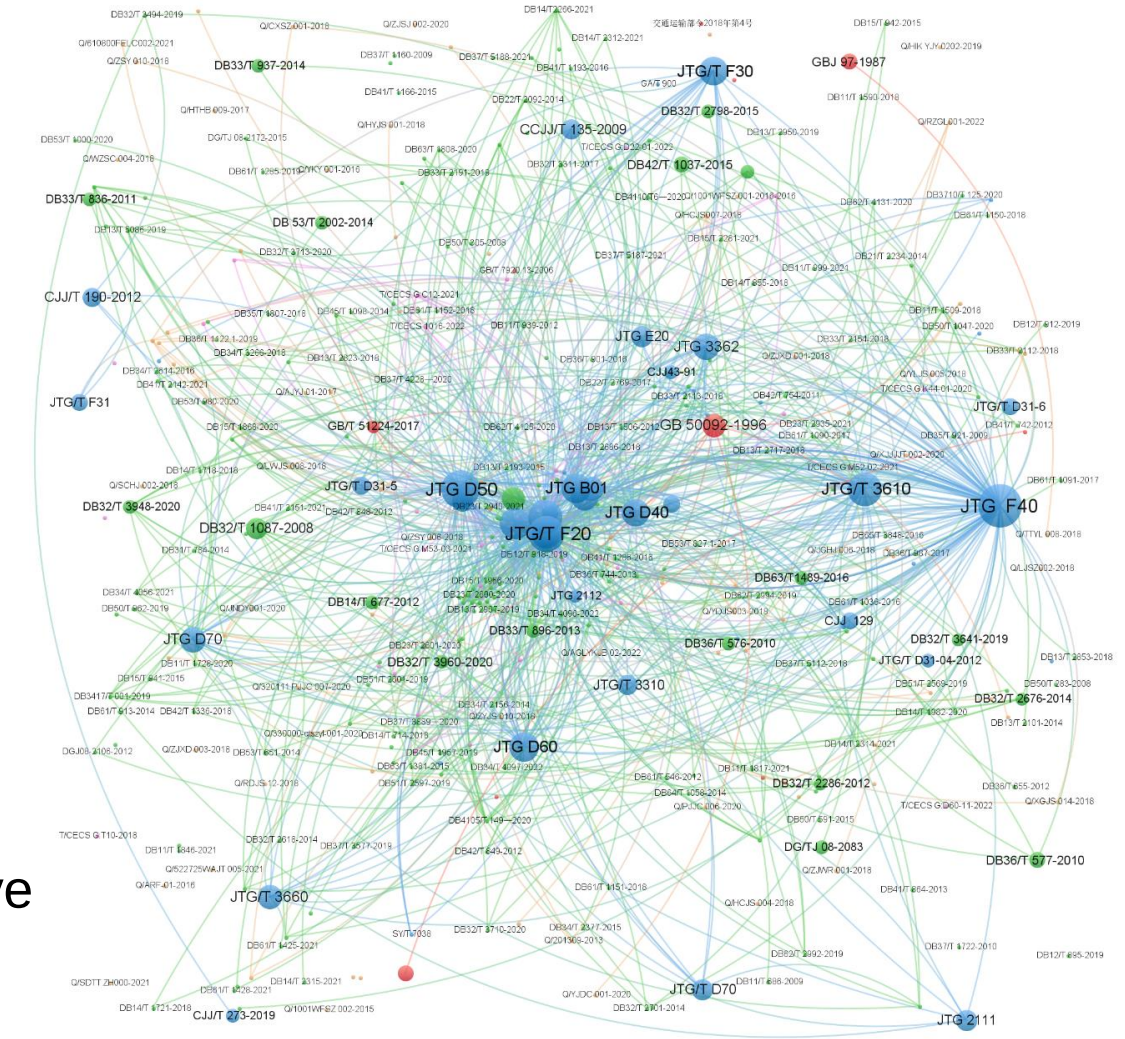
- Constituted by academic / industry association
- Raise the threshold of the industry
- Various and detailed

Standardization plays a fundamental role in road engineering industry. It is important to look into a standardization system with national standards as the leader and ministerial and local standards as the backbone.

2.2 Graph for Road Engineering Standards

The established graph of road engineering standards is a directed network, with a total of 497 nodes and 822 edges:

- Importance analysis on crucial standard nodes in the complex network is made using **degree centrality, semi-local centrality**, and **PageRank** algorithm.
- The three indexes could represent node influence on the **neighbor**, **partial region** and **all networks** separately.
- The Technique for Order Preference by Similarity to an Ideal Solution (**TOPSIS**) is used for comprehensive evaluation because a single evaluation has bias and limitations.



2.3 The Essential Standards

TOPSIS is used for comprehensive evaluation because a single evaluation has bias and limitations. :

- The 20 most essential standards in the graph evaluating by TOPSIS are shown.
- **Ministerial standards** are treated as **the base of** the standards system of road engineering.
- Many other standards including local standards, association standards and enterprise standards **refer to entries and contents** in these ministerial standards.

Standard Name	Rank
Technical Specification for Construction of Highway Asphalt Pavement	1
Specifications for Design of Highway Asphalt Pavement	2
Pavement Base Construction Technical Instructions	3
Specifications for Design of Highway Subgrades	4
Technical Specification for Construction of Highway Subgrades	5
Technical Specification for Construction of Highway Bridge and Culverts	6
Technical Standard of Highway Engineering	7
Technical Specification for Highway Asphalt Pavement Recycling	8
General Code for Design of Highway Bridges and Culverts	9
Technical Guidelines for Construction of Highway Cement Concrete Pavements	10
Specifications for Design of Highway Cement Concrete Pavement	11
Technical Specification for Construction of Highway Road bases	12
Code for Construction and Acceptance of Urban Road Engineering	13
Safety Technical Specifications for Highway Engineering Construction	14
Code for Design of Highway Reinforced and Prestressed Concrete Bridges and Culverts	15
Specifications for Design Highway Tunnels	16
Code for Design of Urban Road Engineering	17
Technical Specification for Construction of Highway Tunnel	18
Code for Pavement Design of Urban Road	19
Code for Construction and Acceptance of Asphalt Pavements	20

2.4 Standard Hotspots: Topic Words Analysis

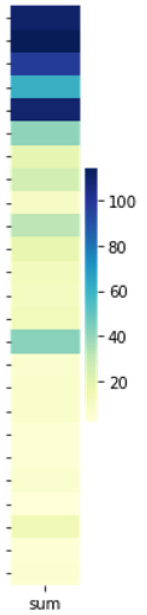
Topic words analysis

- National and Ministerial standards only involve conventional and important topics.

- Topics of local standards are comprehensive, focusing more on modified asphalt, chip seal, mixtures, foamed asphalt and warm mixture which are related to **road performance** and **pollution** except for traditional techniques.

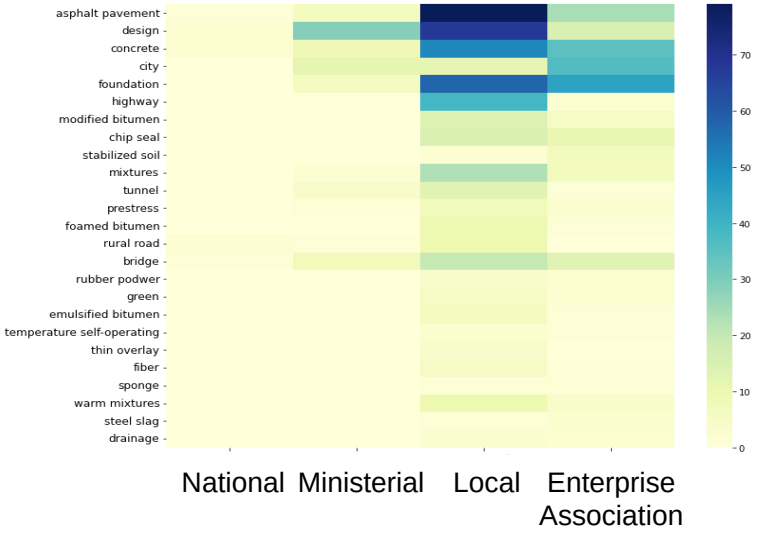
- Topics of enterprise standards and association standards are advanced. Many topics about **energy conservation, environmental protection** and enhancement of infrastructure **resilience** are covered such as rubber powder, green, warm mixture asphalt and steel slag.

Topics focus



asphalt pavement	110
design	114
concrete	97
city	61
foundation	109
highway	41
modified bitumen	19
chip seal	26
stabilized soil	9
mixtures	32
tunnel	18
prestress	12
foamed bitumen	11
rural road	13
bridge	42
rubber podwer	6
green	7
emulsified bitumen	7
temperature self-operating	4
thin overlay	4
fiber	6
sponge	2
warm mixtures	14
steel slag	4
drainage	5

Heated topics distributed in different level of standards

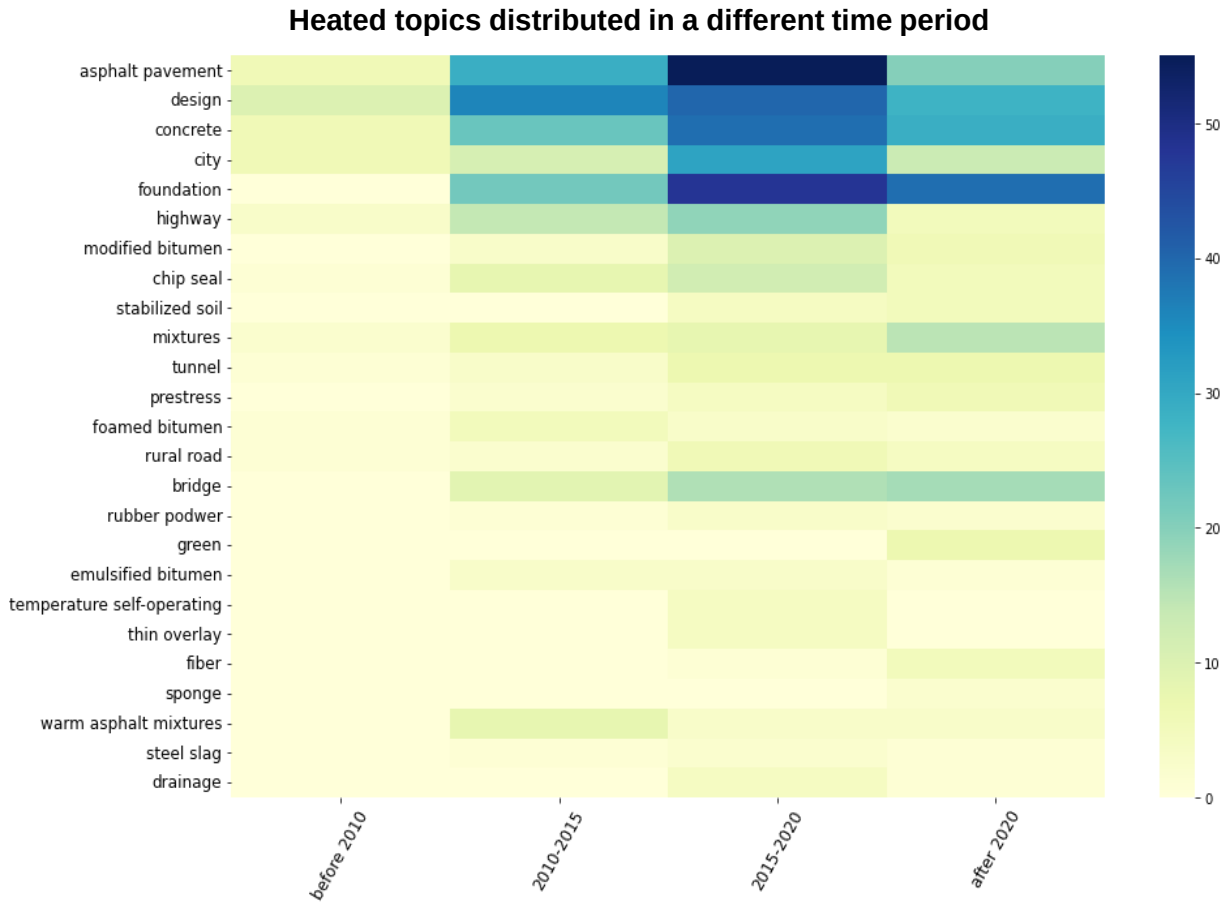


2.4 Standard Hotspots: Topic Words Analysis

Engineering standards have been conducive to promoting the development of corresponding technologies in **environmental protection**, **energy conservation** and **resilience enhancement** since 2010:

- Certain topics have always been important research targets in the transportation infrastructure engineering industry, such as **asphalt pavement, concrete, design, foundation**, etc., which means they play an important role in all periods.

- In addition to conventional topics, other topics are getting more important within periods, and their importance is constantly increasing, such as **mixtures, green, fiber materials, and prestressed.** The change indicates that green and infrastructure resilience are gradually being paid attention to in transportation infrastructure engineering technology.



Technical Features of Road Design and Construction

In China

3.1 Characteristic of Technical Parameters

- Technical parameters in ministerial standards are the basis for designing and construction of highways.
- Ministerial standards regulate mandatory technical parameters for road engineering and they are relatively more **moderate** than other standards.
- Technical parameters of **pavement strength** like CBR value, Deflection Values are essential.
- Concept of "**Strong Base and Thin Pavement**" to prolong the service life of the road
- For the future intelligent and sustainable pavement construction, there is a further improvement in technical parameters and test methods to achieve a more **resilient and comprehensive** standards system.

Subgrade	CBR Value	
	Degree of Compaction	
	Width	
	Transverse Slope	
	Roughness	
	Deflection Values	
	Midline Off-position	
	Grade of Side Slope	
	Longitudinal Height	
Base and Subbase	Quality of Soil	Water Content
		Liquid Limit & Plastic Limit
		Grain Analysis
		Organic & Sulfate Content
	Quality of Coarse Aggregate	Water Content
		Grading
		Liquid Limit & Plastic Limit
		Bulk Specific Gravity & Water Absorption
		Crushed Stone Value
		Clay Content
		Flat-elongated Particle Content
		Soft Stone Content
	Quality of Fine Aggregate	Water Content
		Grading
		Liquid Limit & Plastic Limit
		Bulk Specific Gravity & Water Absorption
		Organic & Sulfate Content
	Quality of Cement	Strength & initial setting time & final setting time
	Quality of Lime	Water Content
		Available Calcium & Magnesium Content
		Residue Content
	Quality of Base & Subbase Mixture	Water Content & Maximum Dry Density
		CBR Value
		Compressive Strength
		Cement & Lime Content

3.2 Standards about “Green” and Resilience

Local Standards

- *DB37/T 5187-2021 Technical specification for construction of central plant hot recycling asphalt pavement in city*
- *DB37/T 5188-2021 Technical Specification for Construction of Foamed Warm-mix Asphalt Mixture Pavement in City*
- *DB22/T 5015-2019 Technical Standards for Recycled Aggregate Road Base Engineering*
- *DB22/T 5015-2019 Technical Standards for Recycled Aggregate Road Base Engineering*

Ministerial Standards

Green and energy-saving concepts start to come out in ministerial standards in recent years:

- *JTG/T 5521-2019 Technical Specification for Highway Asphalt Pavement Recycling* makes rule on a technology that uses recycled asphalt material to pave highways.

Enterprise and Association Standards

- *T/CECS G:C31-2020 Technical Specifications for Soil and Water Conservation for Highway Projects*
- *T/CECS G:C10-01-2020 Technical Standards for Construction of Green Road*
- *Q/321191 JSTN003-2020 Environmentally Friendly Heavy Traffic Road Petroleum Asphalt*

3.3 Sustainable and Resilient Rules

land use and water resources protection

- **Rainwater** engineering : Control non-point source pollution, prevent waterlogging disasters and improve the utilization of rainwater.
- **Subgrade drainage** should be coordinated with the local irrigation and drainage system to avoid pollution of drinking water sources and aquaculture water.
- **Drainage facilities and protective facilities** should be set up. Soil borrowing and spoiling should be specially designed to prevent soil erosion, blocking river channels, inducing roadbed diseases and geological disasters .

protection of ecology and cultural relics

- **Environmental protection** should be considered when selecting **road routes** to reduce the impact on ecology and cultural relics .
- Road construction projects should strictly control the number of **felled trees, retain valuable trees** and take protective measures for **old trees** .
- The **slope protection** design of highways should adopt protective measures.
- The setting of construction spoil piles should be combined with farmland construction and the natural environment and should consider the **protection of forests and farmland**.

pollution problem

- Measures should be taken to control exhaust **emissions and dust** during highway construction.
- Specific sites should be set up in the construction area to **stack production and domestic wastes.**
- **Sludge** produced by road construction should be transported to the designated storage site.
- **Production sewage** and **domestic sewage** in highway construction should not be discharged at will.
- Before using **industrial waste** as road **construction materials**, an environmental assessment should be carried out to meet relevant national regulations.

3.3 Sustainable and Resilient Rules

noise and vibration

- In the sensitive area of the acoustic environment, a relatively gentle longitudinal slope and noise-reduced pavement should be adopted.
- In residential areas or noise-sensitive areas, environmental noise pollution prevention and control measures should be formulated.
- Vibration and noise reduction technical measures such as sound insulation, and installation of vibration damping pads should be adopted for mechanical equipment with strong vibration .
- The selection of construction machinery and equipment should comply with environmental protection regulations.

energy conservation emission reduction and recycling

- Road reconstruction and expansion project could recycle pavement materials and make full use of waste materials.
- The waste asphalt mixture produced by planing and milling the old pavement should be collected and recycled.
- Grinding waste tires into rubber powder for construction is also a better way to deal with waste tires in large quantities and make them recycled.
- For road sections with high environmental protection requirements, warm-mixed asphalt concrete could be used.
- Use technically reliable and economically reasonable local materials during construction.

road resilience

- Design reliability is adopted in the design of the asphalt pavement.
- For highways with heavy or extra-heavy traffic levels, fibers and intermittently graded mixture can be mixed into the asphalt to improve the service life of the pavement.
- Put forward the concept of the functional life of special types of pavement: when the permeable asphalt pavement reaches the functional life, the pavement may be blocked by silt or other sediments, and the surface layer or base layer needs to be repaired.
- Carry out preventive maintenance measures for highway pavement with good surface condition, or slight damage, such as the use of ultra-thin cover, synchronous fiber wear layer, micro-surface, etc.

Representative Road Projects

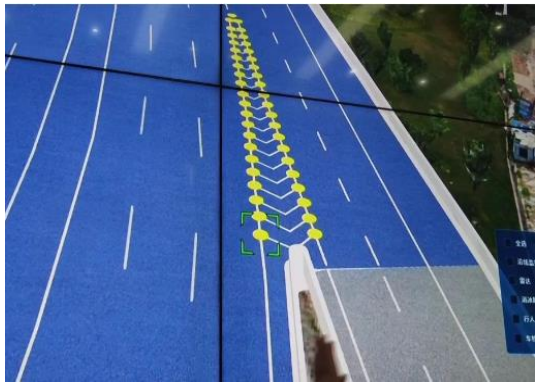
4.1 S342 Smart Highway, Jiangsu

Smart highway pilot project

The S342 Smart Highway in Wuxi provincial highway section, starts from Changshu city in the east and ends at Changzhou city in the west, with a total length of 52.75 kilometers. S342 are parallel to the Shanghai – Nanjing Expressway, which is one of the busiest expressway in China.

- **Panoramic video surveillance**
  - S342 enhances the capacity of **sustainable** and **low-carbon** by improving the efficiency of people and goods transportation and non-motor vehicles' convenience. A total of 4 high-version panoramic video surveillance are deployed at Tianyi Elevated Road, Xigang Road, etc. to monitor road traffic conditions in real-time, which improves the traffic efficiency of the main line.
- **Active monitoring and passive feedback of environmental impact**

  S342 improves the overall **resilience** of the highway by considering the way of active monitoring and passive feedback on the environmental impact.
  - **A highway meteorological monitoring station** is set up in the Huishan Bridge pilot to monitor the meteorological conditions along the highway, including temperature, air pressure, air humidity, rainfall, etc. The monitoring and short-term forecast of disastrous weather can provide early warning of environmental changes.
  - **An intelligent de-icing and snow-removing system** is deployed on Huishan Bridge. When the weather conditions reach the warning threshold, the system will automatically spray a snow-melting agent to quickly melt the snow and ice on the road.
  - **The fog area guidance system** is installed in the section from Huishan Bridge to Tianyi Elevated Road. When the visibility is low, the warning lights and guidance lights on the roadside will "lead the way", and improve the safety preview distance of drivers.



Interchange Panorama Monitoring

Automatic de-icing and snow removal decision system

4.2 G92 Super Highway, Zhejiang

Super highway pilot project

The Hangzhou-Ningbo section of G92 is China's first "smart expressway", with a total length of 161 kilometers and a design speed of 140km/h.

◆ **Green and low-carbon highway**

- Adopting **hot in-place recycling technology**. The technology collects old and new bituminous mixture and adds asphalt and regenerant into a mixing pot to form a new quality asphalt mixture, which greatly reduces carbon emissions from pavement milling and old material transport.
- Using **recycled EPS lightweight mixed soil technology**. By mixing cement, waste soil, EPS particles, coal ash and other additives for EPS lightweight soil mixture, we can dispose the mollisol at the bridge embankment and reduce the use of cement powder piles.

◆ **Advanced driving safety technologies**

- To improve the toughness of the entire line, G92 uses new materials for the pavement to improve the anti-icing ability. For the first time, the G92 test section succeed in using **salted material asphalt mixture** to achieve active highway pavement ice and snow suppression. The salted asphalt mix effectively delayed the onset of pavement icing on the pavement surface.

In-situ thermal regeneration of asphalt

V-260 Snowmelt salting

4.3 G3 Smart Highway, Shandong

The Shandong section of G3 is the most important expressway trunk line in Shandong Province and the pilot construction section of the national forefront of smart highway and smart service areas. Based on the concept of **sustainable development**, the Shandong section of G3 takes into account the **whole life cycle characteristics** of green highway construction. The rationalization of resource utilization in the process of highway construction is considered from design to management to enhance the overall **low-carbon** benefits of the project.

- **Green concept in designing**
  - In the process of highway reconstruction and expansion, G3 separates half width of the work zone and **makes the best use of old road space** to reduce the amount of land acquisition and demolition works and roadbed protection works.
  - In the side slope design, G3 uses **humus utilization, roadside vegetation protection and ecological side ditch** to improve the survival rate of slope vegetation while reducing the destruction of native vegetation.
- **Reducing carbon emissions in the construction stage**
  - Using **asphalt recycling technology** to generate asphalt by ripping up old pavement surfaces which can reduce a large amount of solid waste.
  - Considering the **re-utilization of excavation slags** in the tunnel construction process. The method can reduce transportation consumption and waste of discarded materials.
  - Promoting **the application of energy-saving machinery**. Regularly maintaining machines to ensure the use of good performance and timely replace old and energy-consuming machines in construction to reduce pollution emissions.

Separate half-width construction

In-situ cold recycling of asphalt

4.4 Hong Kong-Zhuhai-Macao Bridge

The Hong Kong-Zhuhai-Macao Bridge is located in the waters of Lingdingyang, connecting Hong Kong Special Administrative Region to the east and Zhuhai City of Guangdong Province and Macao Special Administrative Region to the west.

The bridge aims to **be low-carbon**, **environmentally friendly** and **green**. Because the Hong Kong-Zhuhai-Macao Bridge just happens to pass through the **reserve of dolphins**, in order to achieve the goal of "zero pollution" of the marine environment and "zero casualties" of Chinese white dolphins, the following technical measures were adopted in construction:

- **Construction period planning based on the concept of environmental protection**

  During the feasibility study stage of the project, environmental protection special studies such as environmental impact assessment, sea area use demonstration, **protection of Chinese white dolphins**, marine dumping area selection, and flood control assessment have been carried out. In order to reduce noise during the breeding season, the bridge construction will stop all drilling operations in these two months. When white dolphins are detected during construction, follow the principle of "stop work for observation within 500 meters, and slow down construction beyond 500 meters".

- **Immersed tunnels technologies**

  Adopting advanced construction equipment, innovative construction techniques and an environment-friendly construction plan, which benefits from **shortening offshore construction time** and reducing the sea area occupied.

  Many components such as immersed tube tunnels, bridge caps, and pier bodies are offshore assembled and prefabricated installed, which improves the operation efficiency and shortens the offshore construction time

Zero emission goal of the project

Protection of Chinese white dolphins

4.5 Xi’an Outer Ring Expressway, Shaanxi

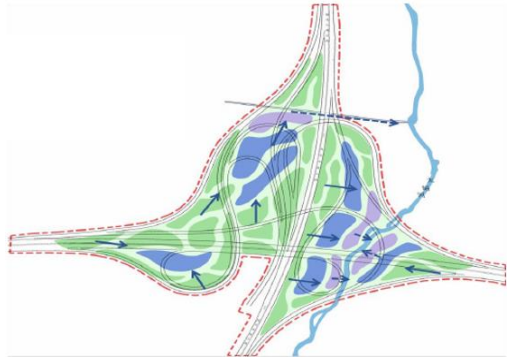
Xi'an Outer Ring Expressway (Southern Section) connects four national expressways and is an important part of Shaanxi Province's "2367" expressway network plan.

- **Ecological route design**
  The road is laid out to avoid as far as possible such environmentally sensitive points as cultural relics, nature reserves and water reserves along the route.
- **Green materials**
  The project combines urban construction waste, high-quality aggregates and cement to produce ecological concrete block products, which are used in the construction of highway facilities with different functions.
- **Energy saving**
  The energy-saving concept is adopted in the design of tunnels. The White Lucerne Tunnel of the expressway is the "Peaceful Centennial Quality Project" loess tunnel project, which chooses low energy consumption of iron-based amorphous alloy transformers to reduce the loss of electricity equipment itself and then reduce the cable line loss.
- **Pollution control**
  The project pays attention to water resource protection, acoustic environment protection, and sponge facilities respectively.

Ecological concrete blocks

The White Lucerne Tunnel

Ecological sound barrier

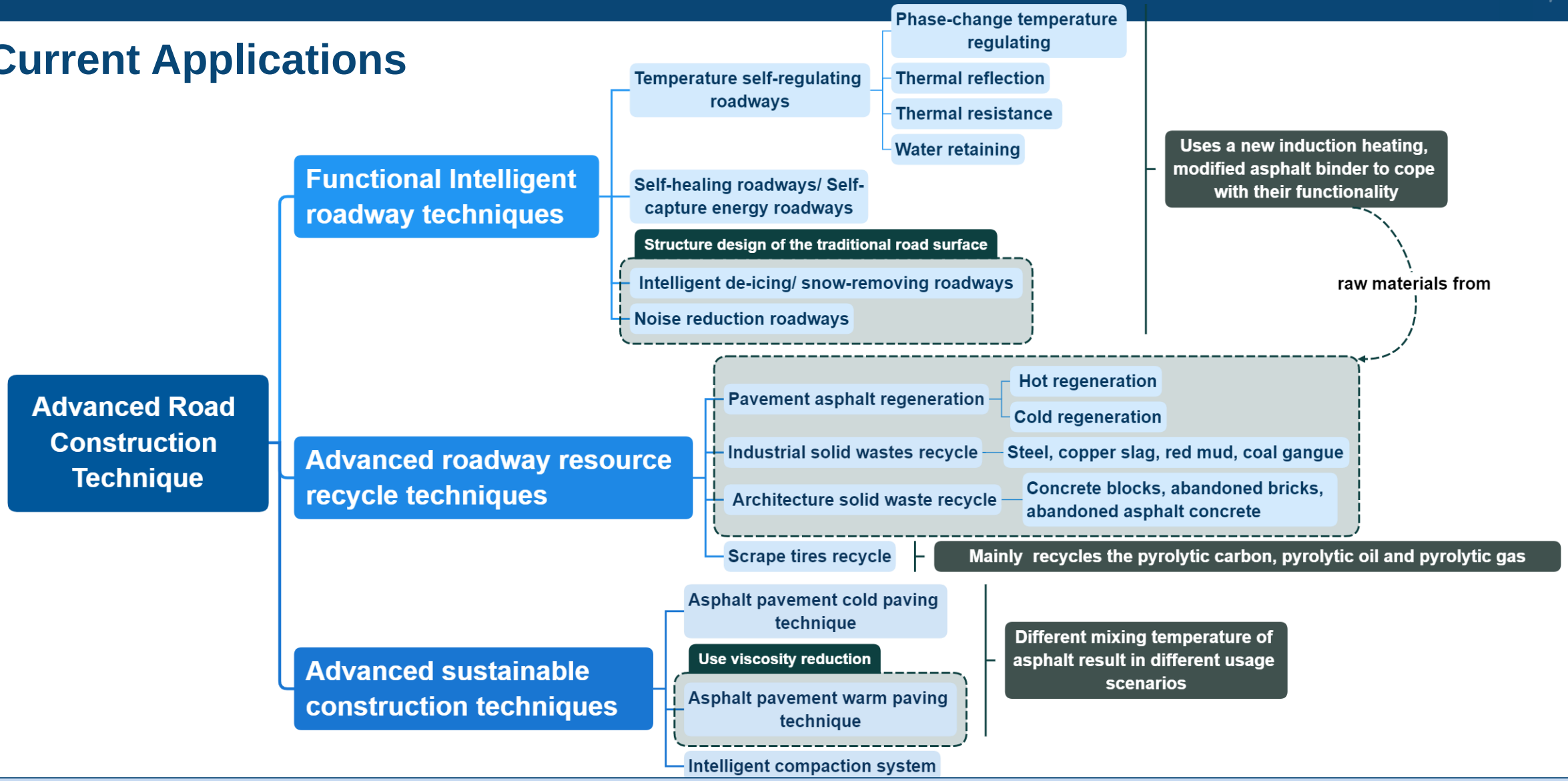


Interchange sponge water collection design

Developmental Trend of Construction Techniques

5.1 Advanced Road Construction Techniques

Current Applications

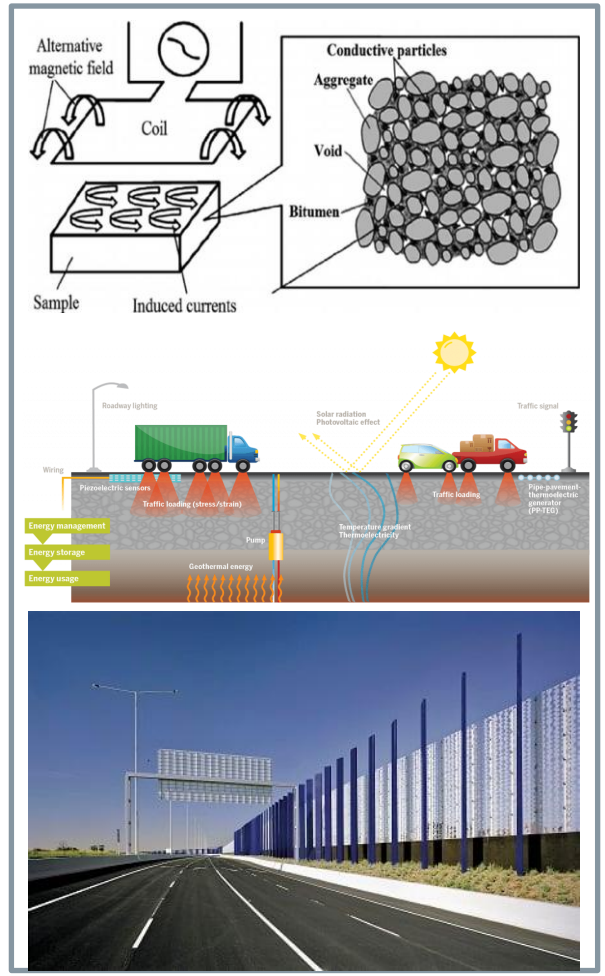


Current mature techniques such as **sustainable and low-carbon pavement materials, advanced road design,** and **intelligent construction**, offering opportunity for more sustainable and intelligent **roadway construction, maintenance,** and **upgradation** in China.

5.2 Functional Intelligent Roadway Techniques

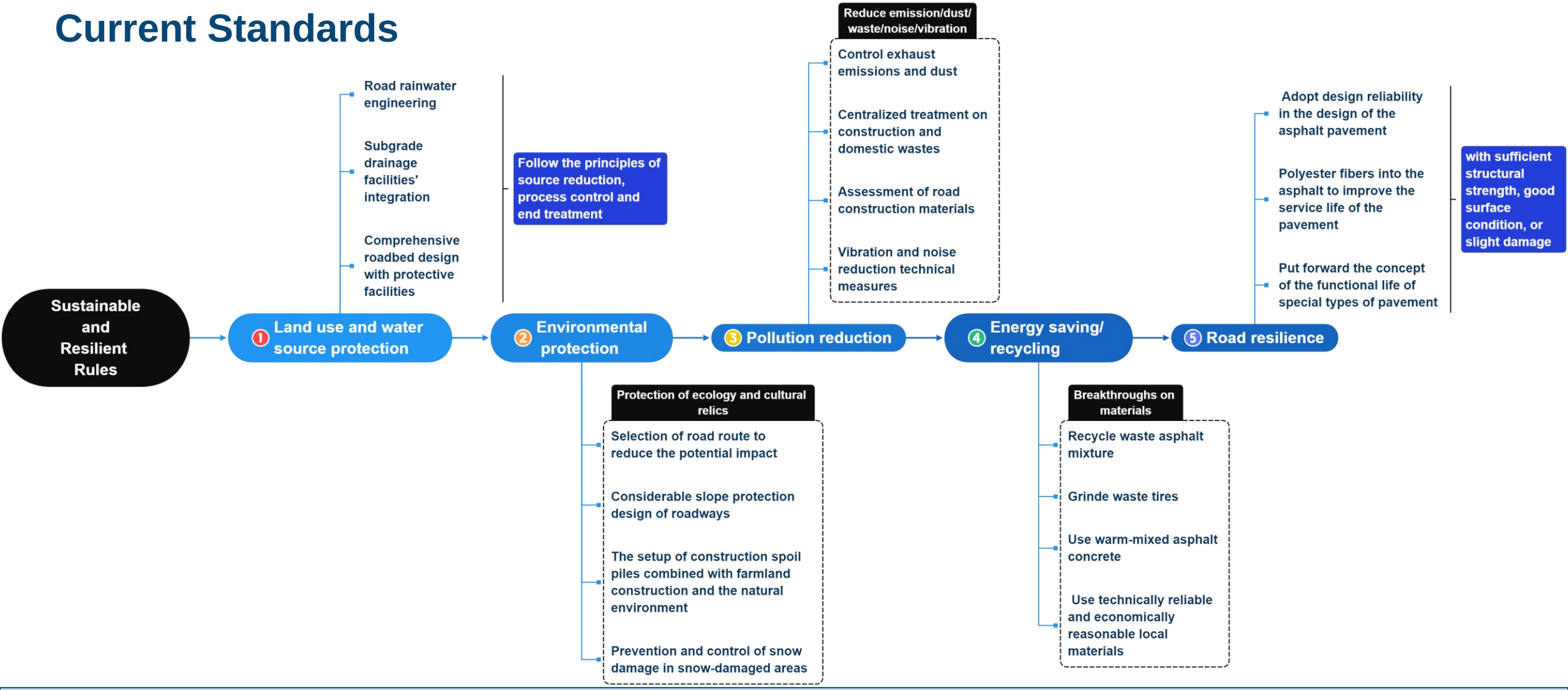
Representative advanced road construction techniques:

- **Temperature self-regulating roadways**
  Uses a new material that can suppress the temperature fluctuation to regulate the roadway temperature, decreasing possibility of rutting, cracks.
- **Self-healing / Self-capture energy roadways**
  Work through the conductive fiber that is added to the asphalt pavement material or filler (such as carbon fiber, graphite, steel fiber and steel slag and conductive polymer polyaniline).
- **Intelligent de-icing and snow-removing roadways**
  Superhydrophobic materials and high elastic materials on the road surface can effectively reduce the amount of ice on the substrate surface and the adhesion between ice and substrate surface.
- **Noise reduction roadways**
  Porous asphalt concrete pavement adopts porous asphalt concrete (PAC) material as pavement material to reduce pavement noise, which can also enhance the acoustic impedance of pavement at the same time.



5.3 Sustainability Rules in Current Standards

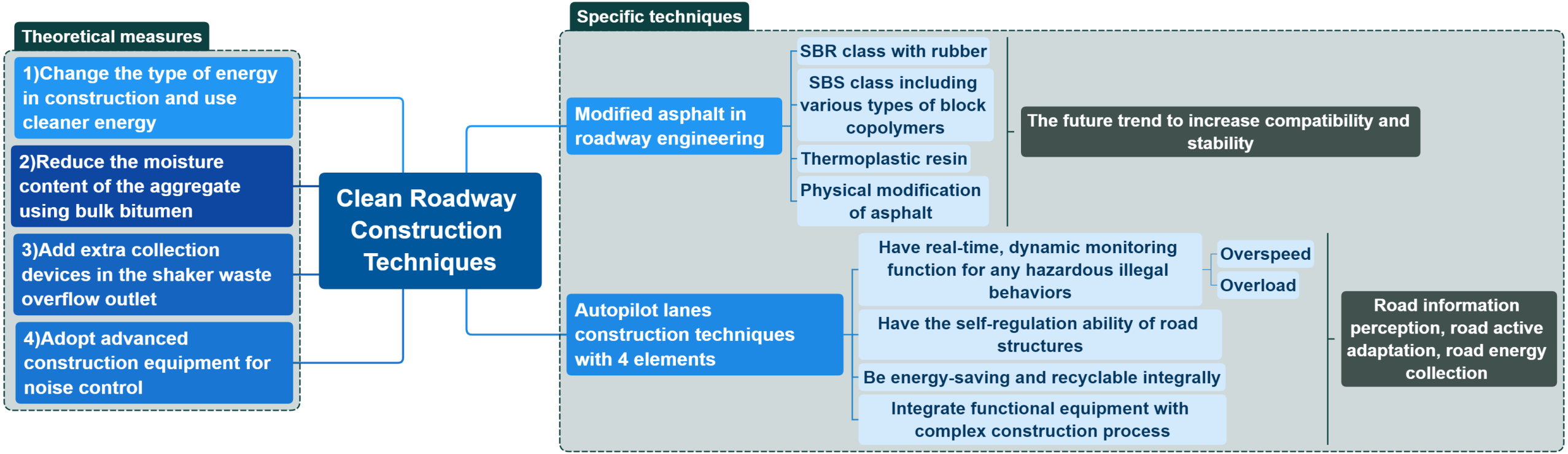
Current Standards



After reviewing all the related standards, construction techniques, and materials, they all summarize and emphasize the rules related to **sustainability** and **resilience** in topography, geology, hydrology, meteorology, ecological environment conditions and existing structures.

5.4 Clean Roadway Construction Techniques

Studies in Current Literature



The trend of future clean roadway construction in China can be described as: in the whole construction process of future roadways, each step in the construction process should follow the **resilient, green and environmental-friendly** rules, to **avoid any possible pollution** to the environment with specific techniques to follow the theoretical measures.

5.5 Modified Asphalt in Roadway Engineering

Representative types of modified asphalt for clean roadway constructions:

- **SBR class**
  This category contains the modified asphalt filled with synthetic rubber and natural rubber, such as natural rubber, neoprene, styrene-butadiene rubber, ethylene propylene rubber, isoprene, ethylene propylene rubber, as well as silicone rubber, fluorine rubber, and waste car tires.
- **SBS class**
  This category includes various types of block copolymers.
- **Thermoplastic resin**
  Thermoplastic resins are materials that soften to a liquid in high heat, and then harden again when cooled. Because of its properties, mixed with thermoplastic materials can make modified asphalt highly recyclable, impact resistance and chemical resistance.
- **Physical modification of asphalt**
  It is mixed with a variety of fiber, grid, geotextile and other modified asphalt.

Summary

6 Summary

- Road construction in China still develops rapidly. **Intelligent system** as well as **new materials and treatment methods** are two research directions in technology development. **Sustainability** and **resilience** are considered as important themes in road engineering development in China.
- By studying standard graph of the whole road engineering industry, the study clarifies the distribution of topics in road engineering standards published in different time periods and at different levels. The topics that are placed more emphasis on are **green and low emission**.
- In examples of smart road project, many new technologies mentioned in recent-published standards are applied into **practice**. As demonstrations of advanced road construction, smart road projects show **ecological and intelligent concepts** and provide good experience for future work.
- Finally, researches on road construction are discussed, with discussions of both current achievements and future trends of road engineering. Corresponding to topic changes in standards and technologies applied in practical projects, research topics focus on **green** and **resilience**, which become generally recognized trends on development of highway construction.

Thank you!

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