Cluster analysis on railway infrastructure standards in China and its application to railway efficiency improvement

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Abstract. The present paper structures an infrastructure standard cluster by studying the attributes, the level of application, and the implementation object of more than two hundred railway infrastructure standards in China. These standards are classified and fitted into different specific categories of the cluster, as a result, a systematic and complete standard cluster forms. A concept of comprehensive standards is put forward during the development of the proposed standard cluster. The proposed cluster could not only guide the preparation of railway standards, improve the economic performance of railway construction, but also helps to enhance the efficiency of the whole railway technical system. Cost reduction for HSR is chosen as an efficiency improvement objective to study how the proposed standard cluster helps to get a set of complete technical solutions. Study results reveal that the cluster can provide a basis for a comprehensive study on specific technical aspects (e.g., cost reduction), and can further extend to a number of applications regarding to efficiency improvement of the railway infrastructure system.

1. Introduction
Railway has been an energy efficient and environmental friendly transportation choice worldwide, it minimizes the energy consumption and cost, reduces the pollutants emissions. Though railway is one of the most energy saving transportation modes, the improvement of working efficiency of railway system is still a significant topic. Railway encompasses a complex reality involving many technical aspects. In accordance with European Railway Agency \cite{1}, railway system can divided into the following four subsystems, i.e., infrastructure, energy, control-command and signalling and rolling stock. The rolling stock subsystem can be further broken down with referencing to EN 15380-4 \cite{2} and EN 15380-5 \cite{3}, in which detailed rules to define the subsystem is presented. EN 15380-1 \cite{4} specifies railway technical project documentation and designation by taking into account the general rules for structuring principles according to EN 61346-1 \cite{5} and designations according to BS/EN 61355 \cite{6}. EN 15380-2 \cite{7} gives a railway product structuring rule, EN 15380-3 \cite{8} specifies guidelines for the designation of installation sites and locations in railway vehicles, EN 15380-4 \cite{2} gives specificaitons for creating functional structures covering functionality associated systems and
equipment. EN 15380-5 [3] defines the System Breakdown Structure (SBS) for railway vehicles and associated principal attributes, in which rules to define the system level is specified.

Some specifications give provisions on technical break-down structuring. It is demonstrated in EN 61346-1 [5] that an object can be successively subdivided into subobjects, which can be represented as a tree-like structure. EN 61346-1 [5] put forward that a standard cluster can be developed with respect to a different type of aspects considered, i.e., function-oriented, product-oriented, project management, material classification. SS IEC 750 [9] also set up tree-like structures even though rules and guidelines on structure development are not specified. The identification number specified in ISO/DIS 1219-2 (1994)[10] implies standards are structured in three levels, i.e., installation, circuit and component. Unlike definite structures mentioned above, EN 61346-2 [11] defines the classification of infrastructure objects but the subclasses are not specified, which are left to be determined depending on the field of application and purpose required. BS/EN 61355 [6] provides international rules and guidelines for the classification of documents covering all technical areas, in which the preparation of a structured documentation is agreed.

Railway infrastructure standards define the rules and guidelines that construction activities must obey, they are important technical bases for the railway construction governance and technical cluster. The establishment of a well-organized railway infrastructure standard cluster could not only benefit standards users (e.g., engineers, infrastructure manager) and standard developers, but also help to better clarify the railway technical cluster and specific technical provisions. One the other hand, a common breakdown of HSR (High Speed-rail, defined as railways with design speed of more than 250km/h) infrastructure cluster into functional and phasic elements is essential. Once a framework of the HSR infrastructure standard cluster is set, it can be used as a universal tool to analyze railway technical matters with a top-down view and make the whole railway technical system more efficient. For example, HSR infrastructure cluster can help to improve the efficiency of HSR cluster, e.g., speed increase, cost reduction, service life increase. To be more specific, the framework can help to scan various aspects of the railway infrastructure cluster during different implementation phases by the identification and evaluation of typical parameters related to cost reduction, thus the working efficiency of the whole railway system can be improved and the emission of pollutants can be reduced as well.

2. Railway technical standards in China
By the end of 2017, the total HSR transportation mileage had reached about 24,000 kilometres in China, which amount to 60% of the world total. HSR lines have covered 28 provinces in China and the HSR network is shaping up. With the construction of HSR lines in China, advanced HSR engineering/construction technologies have been developed, such as complicated soil strengthening methods, long span bridge and large section tunnel construction technologies, track engineering technologies, train control technologies, traction power supply technologies, etc. These practical and proven technologies used in the construction of HSR lines are the bases not only for railway network operation, but also contribute to formation of the whole technical standard cluster, which includes the development of a number of advanced and reliable HSR technical standards in China.

There are more than 1300 railway technical standards in China, which are classified into three main categories, i.e., product standards, operation/maintenance standards and infrastructure standards, as is shown in Figure 1, in which numbers of standards belong to each category are marked in brackets.

Product standards stipulate common practices for railway products during their fabrication, transportation, storage, installation, and acceptance. The railway products in product standards include rolling stock, civil engineering, communication and signalling, traction power supply, and Operation/Service, etc. There are about 800 product standards in China [12], among which 82% are applicable to both HSR and lower speed railway, those applicable to HSR account for 71%. The product standard cluster has been fully developed according to China Railway [12].

Operation/maintenance standards stipulate common practices in terms of management and technicalities during railway operation and maintenance. Operation/maintenance standards cover such
fields as train operation, locomotive, rolling stock, passenger transport, freight transport, track maintenance, power supply, communication, signalling, information, etc. They consist of management regulations and technical regulations, the latter can be subdivided into Basic Regulations, Cluster Regulations, Specialized Regulations, and Interim Regulations. The classification schematic of operation/maintenance standards is shown in Figure 2, in which the numbers in parentheses indicate the number of standards contained in each of the four categories by the end of 2017.

![Figure 1. Three types railway technical standards in China.](image1)

![Figure 2. The classification schematic of operation/maintenance standards.](image2)

There are more than 200 railway infrastructure standards in China which stipulate the common practice at survey, design, construction, and acceptance stages. Unlike product standards and operation/maintenance standards for which well-organized standard clusters have been developed, the railway infrastructure standard cluster is not complete at present. In an attempt to clarify the interfaces between different standards, avoid repetition and confliction between standards, a railway infrastructure standard cluster is proposed in this paper. Another motivation for building a complete infrastructure framework is providing a tool to obtain specific design and technical requirements during efficiency increase.

3. Cluster analysis for railway infrastructure standards in China

3.1. Cluster analysis method

Conceptual(or shared-property) clustering is a modern categorization approach based on concept analysis. In this method, concepts (or representations) of clusters are firstly developed with the formulation of conceptual descriptions, and then the objects can be categorized by referring to the developed descriptions. Most conceptual(or shared-property) clustering approaches generate hierarchical cluster structures, which are closely related to the Hierarchical cluster analysis (HCA). As a statistical tree-based approach, HCA identifies distinguishable clusters by checking over the dissimilarities and similarities between objects. This approach is appropriate to be used in the analysis of relatively small data sets. This paper combines the above mentioned two theories to form the Hierarchical conceptual clustering method for standard cluster analysis. Specifically, the main clustering process of standards involves the following steps:

- Propose the concepts (or representations) for each cluster or subcluster;
- Identify the standards that share similar commonalities and put the standards as the objects within an identical cluster;
- Visualization of the cluster structure. Using the leaf to represent each standard, branching to represent the relationships between clusters, a hierarchical(tree-like) configuration namely dendrogram is formed to visualize the cluster structure.

3.2. Results of cluster analysis

During the cluster analysis process, different concepts (or representations) for clustering are proposed considering the attributes, level of application, and implementation object of each standard. Three
fundamental concepts(i.e., basic, comprehensive and specialized) are introduced from the top-level perspective, thus the whole infrastructure standards can be divided into three subclusters, namely basic standards, comprehensive standards, and specialized standards, as is shown in Figure 3.

**Figure 3.** Proposed three categories of railway infrastructure standards.

3.2.1. **Basic standards** Basic standards are defined as the basis of infrastructure standards, which are proposed to be further broken down into the following 8 subclusters,

- Standards for terms and symbols
- Standard for design load, i.e., *Code for Train Load Diagrams*(TB/T 3466-2016).
- Environmental protection standards, i.e., *Guide for the Construction of Green Corridor for Railways and Evaluation Standard for Green Railway Passenger Stations* (TB10429-2014).
- Energy saving standards, i.e., *Code for Design of Energy-Saving of Railway Engineering* (TB10016-2006)
- Safety standards, which related to railway risk management, disaster prevention and mitigation, anti-terrorism and explosion protection, construction safety and other technologies, i.e., *Technical Specification for Basic Operation Safety of Railway Engineering* (TB10301-2009) and *Code for Labor Safety and Health Design of Railway Engineering* (TB10061-1998)
- Fire prevention standards, i.e., *Code for Design on Fire Prevention of Railway Engineering* (TB10063-2007)
- Anti-seismic standards, i.e., *Code for Seismic Design of Railway Engineering* (GB50111-2006)

The subcluster of standards for terms and symbols is proposed to contain the following 3 standards,

- *Drawing Standards of Railway Engineering* (TB/T 10058-2015)
- *Basic Terms for Railway Engineering* (GB/T 50262-2013)
- *Standard for Graphical Symbol of Railway Engineering* (TB/T 10059-2015)

In general, the proposed categories of basic standards are shown in Figure 4.

**Figure 4.** Proposed categories of basic standards.

3.2.2. **Comprehensive standards** The cluster of comprehensive standards is defined to include specifications which are applicable to different engineering fields, i.e., earthworks, bridge, tunnel, track, communication, signalling, traction power supply, etc. Comprehensive standards are proposed to be further divided into four subclusters, i.e., survey standards, design standards, construction standards and acceptance standards. Figure 5 is the schematic of proposed categories of comprehensive standards.
Figure 5. Proposed categories of comprehensive standards.

Survey standards mainly include geological investigation and engineering survey standards. We fit different elements into 4 categories of comprehensive standards, as is shown in Figure 6, and 3 standards are selected for further explanation,

*Code for Geological Investigation in Railway Engineering (TB10012-2007)* is fit into the survey subcluster within the comprehensive standards cluster, which stipulates basic provisions on geological investigation methods, the investigation process, and the basic requirements on investigation for bridges, tunnels, earthworks, buildings, etc., covering geological investigation provisions during the design, construction, and operation stages.

*Code for Design of Railway Line (GB50090-2006)* is located in the design subcluster, which provides basic design provisions on railway line plan, railway line profile, station location, etc.

*Technical Specification for Construction of High-speed Railway Tunnel (Q/CR 9604-2015)* is proposed to be an element of the construction subcluster, which gives basic construction provisions on preparation, portal, tunnelling, supporting, lining, monitoring, waterproofing and drainage, ventilation, etc.

3.2.3. Specialized standards. To form the structure of the infrastructure standards system, the cluster of specialized standards includes standards that provide supplement and extend provisions for comprehensive standards, these standards gather up according to their specific engineering fields such as survey, infrastructure, communication and signalling, energy and interface.

The subcluster of specialized standards can be further breakdown into four categories, i.e., earthworks, tunnel, bridge and others. The proposed subcluster of specialized standards and its breakdown structure are shown in Figure 7, in which the infrastructure category named "others" are gathered up by standards that are hard to be classified into a specific field, e.g., standards specifying multimodal transport, the cross-over of railway and municipal engineering/ oil and gas pipelines, BIM technology.

We fit different elements of standards into 5 categories of specialized standards, as is shown in Figure 8, and 2 standards are selected for further explanation:

*Code for Design of Auxiliary Power Supply in Traction Substation (TB10080-2002)* can be located in the energy category of specialized standards, which particularly stipulates conditions under which AC or DC is shall be used, the requirements on current and voltage, and the configuration of equipment concerned.

*Standard for Acceptance of CRTSⅢ Track for High Speed Railway(2014)* is an element of the infrastructure category of specialized standards, which stipulates specifications on requirements, activities and processes for the acceptance of CRTSⅢ track in terms of product site inspection, ballastless track construction (base, track slab laying, self-compacting concrete, etc.), CWR laying, and track adjustment.
Figure 6. Comprehensive Standards fitted into the stages of survey (a), design(b), construction (c), acceptance(d).

Figure 7. Proposed categories of specialized standards.

By cluster analysis, each standard, as well as the provision inside, can be well organized and distributed into different divisions, as a result, the efficiency of standard cluster increases. Figure 9 gives a whole schematic of the infrastructure standard cluster which contains subclusters and categories.

3.3. Discussion
The proposed railway infrastructure standard cluster established above is a complete cluster featured in the following aspects: (1) The cluster contains standards that stipulate requirements in fabrication, transportation, storage, installation and acceptance of railway products, as well as the operation/maintenance requirements. It also covers various engineering fields such as earthworks, bridge, tunnel, track, communication and signalling, and energy; (2) The proposed cluster contains
standards that specify provisions in various climatic, topographic and geological railway implementation conditions, as well as with various types and speeds of transport demand.

| Specialized Standards | Specialized Standards |
|-----------------------|-----------------------|
| **Survey**            | **Infrastructure**    |
| Code for General Survey of Geotechnical Conditions Investigation of Railway Engineering (TB10015-2015) | Code for Design on Subgrade of Railway (TB0101-2000) |
| Specification for Investigation of Special Rock and Soil for Railway Engineering (TB10016-2010) | Code for Design on Special Subgrade of Railway (TB0101-2000) |
| Specification for Engineering Geotechnical Survey of Current Construction Site for Railway (TB10017-2015) | Technical Specifications for Continuation Construction Control of Railway Subgrade (QCR 9210-2015) |
| Code for Investigation of Railway Engineering (TB1008-2014) | Technical Code for General Treatment of Railway Engineering (TB0803-2080) |

Figure 8. Specialized standards fitted into the fields of survey (a), infrastructure-earthworks(b1), infrastructure-tunnel(b2), infrastructure-bridge(b3), infrastructure-others(b4), communication and signalling(c), energy (d).

4. Efficiency improvement objective: cost reduction

There are several important aspects of HSR efficiency improvement, such as speed increase, cost reduction, service life extension. Among these aspects, we choose HSR cost reduction as an efficiency improvement objective to study how the proposed infrastructure standard cluster help to get a set of complete technical solutions to infrastructure cost reduction. Our study follows the phases listed below:

1. Go through the standard cluster proposed above and pick up standards related to HSR construction cost;
2. Identify representative parameters/provisions that constraint cost reduction of the selected standards;
3. Analyze the relationship between the parameters/provisions and cost reduction, make reliable parameter/provisions adjustment in an attempt to reduce construction cost;
(4) Form a set of complete technical solutions to cost reduction.

HSR infrastructure is a complex system integrating railway alignment, earthworks, bridge, tunnel, track, railway station and building, maintenance facilities, etc. It is impossible to evaluate and exhibit every engineering aspects that have an influence on construction cost in a single paper, thus we select the element of railway alignment to explain how solutions to cost reduction can be found, other infrastructure elements except railway alignment can also refer to the study procedure.

Following the above mentioned study phases (1)-(4), we go through the proposed standard cluster and pick up related standards, i.e, *Code for Design of Railway Line (TB 10098-2017)*, *Code for Design of Railway Continuous Welded Rail (TB 10015-2012)*, *Code for Design of Railway Line (GB50090-2006)*, *Code for Design of High Speed Railway (TB 10621-2014)*, etc. Then we identify representative parameters that have significant influence on construction cost in the selected standards. Tab. 1 shows some of the identified parameters.

**Table 1.** Some examples of parameters that identified by analysis of these standards.

| Area          | Element          | Parameters                                                                 |
|---------------|------------------|---------------------------------------------------------------------------|
| Railway alignment | Maximum design cant |                                                                                   |
|               | Cant deficiency  |                                                                            |
|               | Cant excess      |                                                                            |
|               | Minimum curve radius of horizontal curve |                                                                                   |
|               | Distance between centers of tracks |                                                                                   |
|               | Length of transition curves |                                                                                   |
| Infrastructure | Minimum length of circular curves/straights between two transition curves |                                                                                   |
|               | Minimum length of grade section |                                                                                   |
|               | Minimum radius of vertical curve |                                                                                   |
| Earthworks    | Width of subgrade surface |                                                                                   |
|               | Safety factor (FOS) for the slopes of embankment |                                                                                   |
|               | Post-construction settlement limit |                                                                                   |
|               | Physical parameters of fill material |                                                                                   |
|               | Compaction criteria of fill material |                                                                                   |
|               | ...               |                                                                            |

Once the cost-related parameters are identified and their reference values are specified, finding possible cost-reduced meanwhile reliable solutions is possible. Series of systematic researches (J2017Z509, 2017B001-C) have been carried out by China Railway since 2015 to optimize HSR railway infrastructure design parameters so as to reduce infrastructure cost, in which different methods
including data analysis, numerical simulation, test examination, practice validation, etc are included [13]. It is found in these researches that some parameters are greater than those required by train running stability and passenger comfort, which have repercussions on infrastructure costs. In an attempt to reduce infrastructure cost, the values of these parameters are recommended to be modified to specific values. As the research work is huge, adjustment results of railway alignment parameter are given in this paper while detailed analysis method is omitted. Tab.2 lists recommended limit values of identified parameters according to Gianpiero Pavirani [14], and gives the reference values in current standards for comparison.

Parameters and limit values shown in Tabs.1-2 are only limited to railway alignment, specific infrastructure elements including earthworks, bridges, tunnels, etc shall also be carried out by referencing above methods if we want to get complete cost reduction solutions. Based on the above verification, we can see that the proposed infrastructure standard system is a helpful tool to identify each element of the infrastructure cluster, and provide a basis for a comprehensive study on efficiency increase of HSR.

**Table 2.** Recommended limit values of identified parameters and the limit values in current standards.

| Parameters | Limit values according to current standards | Recommended limit values by analysis |
|------------|--------------------------------------------|-------------------------------------|
| Distance between centres of tracks | | |
| 250km/h | 4.6m | 4.4m |
| 300km/h | 4.8m | 4.6m |
| 350km/h | 5.0m | 4.8m |
| Cant deficiency and cant excess | | In sections, limit values remain the same. |
| Cant deficiency for Ballasted track: 179mm; for Ballastless track: 175mm | Ballasted General conditions 3300m | 300km/h Difficult conditions 3000m |
| | Ballasted Difficult conditions 4000m | |
| | Ballasted General conditions 5000m | 350km/h Difficult conditions 4700m |
| | Ballasted Difficult conditions 5000m | |
| | Ballasted General conditions 6000m | |
| | Ballasted Difficult conditions 7000m | |
| | Ballasted Difficult conditions 7500m | |
| Minimum curve radius of horizontal curve | | In sections, limit values remain the same. |
| Ballasted | General conditions 3300m | 300km/h Difficult conditions 3000m |
| Ballasted | General conditions 5000m | |
| Ballasted | General conditions 5000m | |
| Ballasted | General conditions 6000m | |
| Ballasted | General conditions 7000m | |
| | Ballasted Difficult conditions 7500m | |
| Length of transition curves | Change rate of cant | General conditions 31mm/s |
| Excellent 2.5mm/s | Ballasted General conditions 3300m | 250km/h Difficult conditions 45mm/s |
| Fine 2.8mm/s | Ballasted General conditions 40mm/s | 300km/h Difficult conditions 40mm/s |
| Poor 3.1mm/s | Ballasted General conditions 31mm/s | 350km/h Difficult conditions 31mm/s |
| | Ballasted Difficult conditions 35mm/s | |
| Minimum length of circular curves/straights between two transition curves | General conditions L≥0.8V | General conditions L≥0.6V |
| Difficult conditions L≥0.6V | Difficult conditions L≥0.4V | 25000m In sections where vertical curve and circular curve overlaps, Minimum curve radius of vertical curve shall be 3500m in general conditions, or 3000m in difficult conditions. |
| | | 30000m In sections where vertical curve and circular curve overlaps, Minimum curve radius of vertical curve shall be 5000m in general conditions, or 4500m in difficult conditions. |
| | | 15000m In sections where vertical curve and circular curve overlaps, Minimum curve radius of vertical curve shall be 7000m in general conditions, or 6000m in difficult conditions. |

*......*
5. Conclusions

Fitted in the proposed railway infrastructure standard cluster, different standards are independent and coordinate with each other, as a result, a systematic and complete standard cluster forms. This cluster involves standards concerning infrastructure, communication signals, traction power supply and large-scale stations, it could not only guide the preparation of railway standards, improving the economical performance in railway construction, but also enhance the efficiency of the whole railway technical system. The proposed railway infrastructure standard cluster can be also applied to form standard clusters in other countries/regions. The chosen working methods, starting from a shared architecture of the railway infrastructure cluster, to identification of each element gathered by classified standards from the various railway networks, a tool that can be used for a number of specific applications regarding HSR infrastructure cluster is created. We choose cost reduction for HSR as an efficiency improvement objective to study how the proposed standard cluster help to get a set of complete technical solutions.

It deserves to be mentioned is that our research is based on current published railway infrastructure standards in China, the cluster development principle proposed in this paper can be adapted to establish a cluster for specifications on other fields in different countries, and the technical analysis method proposed in this paper can be used to analyze other technical matters effectively as well. It should also noted that the cluster analysis results are somewhat subjective because they significantly depend upon the authors’ choices.

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