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The City Intelligence Quotient (City IQ) Evaluation System: Conception and Evaluation

Zhiqiang Wu [a,*], Yunhe Pan [b], Qiming Ye [a], Lingyu Kong [a]

[a] Tongji University, Shanghai 200092, China
[b] Chinese Academy of Engineering, Beijing 100088, China

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ABSTRACT

After a systematic review of 38 current intelligent city evaluation systems (ICESs) from around the world, this research analyzes the secondary and tertiary indicators of these 38 ICESs from the perspectives of scale structuring, approaches and indicator selection, and determines their common base. From this base, the fundamentals of the City Intelligence Quotient (City IQ) Evaluation System are developed and five dimensions are selected after a clustering analysis. The basic version, City IQ Evaluation System 1.0, involves 275 experts from 14 high-end research institutions, which include the Chinese Academy of Engineering, the National Academy of Science and Engineering (Germany), the Royal Swedish Academy of Engineering Sciences, the Planning Management Center of the Ministry of Housing and Urban-Rural Development of China, and the Development Research Center of the State Council of China. City IQ Evaluation System 2.0 is further developed, with improvements in its universality, openness, and dynamic adjustment capability. After employing deviation evaluation methods in the IQ assessment, City IQ Evaluation System 3.0 was conceived. The research team has conducted a repeated assessment of 41 intelligent cities around the world using City IQ Evaluation System 3.0. The results have proved that the City IQ Evaluation System, developed on the basis of intelligent life, features more rational indicators selected from data sources that can offer better universality, openness, and dynamics, and is more sensitive and precise.

1. Classification of existing intelligent city evaluation systems (ICESs)

1.1. Features of existing ICESs

Because intelligent city evaluation systems (ICESs) are established with diverse purposes, by multiple subjects, and for diverse objects, there have been no unified standards for ICESs on a global scale [1]. Currently, 38 independent ICESs can be identified worldwide, having been established in East Asia, Europe, North America, and Oceania. The creation of these 38 systems involves 20 university research teams, 8 governmental departments, and 10 business enterprises and associations, and covers the time period from 1995 to 2015, see Table 1 [2–23]. Some systems, such as the TU Wien System [2] and the Intelligent Community Forum (ICF) System [3], are still under continuous development.

The tertiary indicators of these 38 systems are all quantifiable. Only 17 of the 38 consist of integrated primary, secondary, and tertiary indicator systems, and out of these 17 only the GONG Bingzheng System [24] and the China Wisdom Engineering Association System [25] have quantifiable secondary indicators. Therefore, for practical purposes, contradictions can occur between the assessment results derived from secondary indicators and the results derived from tertiary indicators within the same

* Corresponding author.
E-mail address: wus@tongji.edu.cn

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Table 1
The 38 intelligent city evaluation systems (ICESs) from around the world.

No.	ICES	Year	Sponsor	Research team	Resarch approach	Number of primary indicators	Content of primary indicators	Number of secondary indicators	Number of trinary indicators
1	Australian System	2004	State government	Australian government	AHP	8	Technical dimension, Internet use, access level, infrastructure dimension, use, cose, e-commerce, e-governance	0	29
2	Japanese System	2005	State government	Japanese government	AHP	5	ICT expense rate, ICT quality, ICT mobility, ICT popularization, ICT construction	0	10
3	Nanjing System	2010	Local government	Xianfeng Deng	AHP	4	Internet field, industrial field, service field, humanity and culture field	0	24
4	Hubei System	2011	Local government	Xianyi Li, Boya Cheng	AHP	4	Ubiquitous network, intelligent application, public support platform, value recognition	19	57
5	Ningbo System	2012	Local government	Dedao Gu, Wen Qiao	AHP	7	Intelligent class, intelligent infrastructure, intelligent governance, intelligent livelihood, intelligent economy, intelligent environment, intelligent planning and construction	21	48
6	Shanghai Pudong System	2012	Local government	Shanghai Pudong Smart City Research Institute	AHP	5	Infrastructure, public management and service, information service for economic development, humanity and science attainment, citizen awareness	18	37
7	National Pilot Intelligent City Indicator System	2012	Professional administrative department	Ministry of Housing and Urban-Rural Development (MoHURD)	AHP	4	Security system and infrastructure, intelligent construction and livability, coordination and service management, intelligent industry and economy	11	59
8	Ministry of Industry and Information Technology System	2013	Professional administrative department	Ministry of Industry and Information Technology (MIIT)	AHP	3	Intelligent preparation, intelligent management, intelligent service	9	45
9	Richard Florida System	2002	Academic team	Richard Florida	AHP	3	Residents' innovation potential, collective intelligence, environmental intelligence	3	3
10	TU Wien System	2007	Academic team	Rudolf Giffinger	AHP	6	Intelligent economy, intelligent population, intelligent governance, intelligent mobility, intelligent environment, intelligent living	31	74
11	Lazaroiu System	2007	Academic team	George Cristian Lazaroiu	AHP	4	Intelligent economy, intelligent governance, intelligent environment, intelligent energy and mobility	0	18
12	Donato Toppeta System	2010	Academic team	Donato Toppeta	AHP	6	Economy 2.0, human resource and social capital development, e-democracy/government 2.0/intelligent government, information mobility and intelligent transportation system, eco-system, life quanlity and sustainability	0	11
13	MAO Yanhua System	2012	Academic team	Yanhua Mao	AHP	7	Intelligent class, intelligent infrastructure, intelligent governance, intelligent livelihood, intelligent economy, intelligent environment, intelligent planning and construction	23	42
14	LU Yanping Information Industry Competitiveness System	2012	Academic team	Yanping Lu, Ping Hu	AHP	3	Comprehensive economy, technological innovation, environmental support	9	24
15	LI Jian System	2012	Academic team	Jian Li, Chunmei Zhang	AHP	3	Application performance, information infrastructure, practical application effect	3	–
16	Karima Kourtit System	2012	Academic team	Karima Kourtit	AHP	3	Prosperous commerce and social-cultural attraction, labor and municipal facility capacity, high-end e-service usage	0	11
17	Patrizia Lombardi System	2012	Academic team	Patrizia Lombardi	SDA	6	Universities, knowledge, industry, market, government, learning	0	6

continued

No.	ICES	Year	Sponsor	Research team	Resarch approach	Number of primary indicators	Content of primary indicators	Number of secondary indicators	Number of trinary indicators
18	GUO Xirong System	2013	Academic team	Xirong Guo, Xianfeng Wu	AHP	5	Infrastructure, public management and servie, information service for economic development, humanity and science attainment, citizen subjective experiencing	19	–
19	HUANG Shaohui Evaluation System	2013	Academic team	Shaohui Huang, Xizhao Zhou	SDA	4	Infrastructure network, public administration and service, industry and economic development, humanity and science attainment	0	51
20	LIU Xiaoyin System	2013	Academic team	Xiaoyin Liu, Shurong Zheng	MCA	4	Information infrastructure, public supporting platform, city competitiveness, value realization	0	19
21	WANG Zhenyuan System	2013	Academic team	Zhenyuan Wang, Yongjia Duan	AHP	3	Intelligent infrastructure, public administration application, public service application	0	47
22	ZHOU Ji DPSIR Model	2013	Academic team	Ji Zhou	FCE	5	Driving, pressure, state, impacts, responses	0	37
23	CHANG Wenhui System	2014	Academic team	Wenhui Chang	AHP	5	Municipal governance capacity, city operation capacity, eco-management, personal service, enterprise service	26	–
24	XIANG Yong System	2014	Academic team	Yong Xiang, Hong Ren	ANP + TOPSIS	5	Infrastructure, public management and service, information servie for economic development, humanity and science attainment, citizen objective experiencing	19	60
25	GONG Bingzheng System	2015	Academic team	Bingzheng Gong	AHP	3	Construction environment, construction performance, economic benefits	11	33
26	LIU Weiyue System	2015	Academic team	Weiyue Liu, Hailong Wang, Kaige Liu	TOPSIS	4	Urban management, innovation and intelligence, environment protection and culture, livability and livelihood	0	10
27	ZOU Kai System	2015	Academic team	Kai Zou, Minglin Bao	GRA-BP	5	Economic development potential, social development potential, public services potential, scientific and technological innovation potential, information infrastructure	0	21
28	XIAO Yongjun System	2015	Academic team	Yongjun Xiao	MCA	4	Information infrastructure, technological innovation, city development competitiveness, industrial structure	0	19
29	ICF System	2001	Professional association	Intelligent Community Forum (ICF) Institute	AHP	4	Broadband, innovation, digital inclusion, marketing and advocacy	18	14
30	World Economic Forum System	2001	Professional association	World Economic Forum	AHP	3	Environment sub-index, preparedness index, usage sub-index	9	68
31	Group of Seven System	2002	Professional association	Group of Seven	AHP	4	Environment, readiness, application, impact	12	116
32	Sustainable Global City Association System	2002	Professional association	Sustainable Global City Association	AHP	7	Compact land use, green building, green transportation, ecological protection and cultivation, energy conservation and use, municipal facilities, intelligent interconnection	0	110
33	China Wisdom Engineering Association (CWEA) System	2011	Professional association	China Wisdom Engineering Association	AHP	3	Happiness indicator, management indicator, social responsibility indicator	22	86
34	Korea Computerization Agency System	1995	Enterprise	Korea Computerization Agency	AHP	4	Computer, Internet, telecom, radio and broadcast	0	6
35	IBM Evaluation Matrix	2010	Enterprise	IBM Corporation	AHP	7	Transportation, communication, water, energy, city service, citizens, commerce	0	64
36	IDC Smart City Index	2011	Enterprise	Int'l Digital Corporation	AHP	5	Government, buildings, transportation, energy, environment and service	23	94
37	GMTECH Evaluation System	2014	Enterprise	GMTECH Corporation	AHP	6	Infrastructure, governance, livelihood, industry, population class, environment	15	39
38	NSCI System	2010	Enterprise	Ericsson Corporation	AHP	6	Society, economy, environment, infrastructure, affordability, application	15	–

Table by City IQ research team, 2013, 2014, 2015. Source: Refs. [2–23].
ICT: information and communications technology; AHP: analytic hierarchy process; SDA: structural decomposition analysis; MCA: multi-criteria analysis; FCE: fuzzy comprehensive evaluation; ANP: analytic network process; TOPSIS: technique for order preference by similarity to an ideal solution; GRA: grey relational analysis; BP: back propagation.

evaluation system. Of the 38 ICESs, 17 consist of only primary and tertiary indicators; and the systems of IBM and NSCI are relatively exceptional cases, both of which feature a matrix format [26].

The content of the indicator dimensions reflects the key elements of a specific ICESs [27], and is thus of value as an orientation function. A quantitative study of 20 indicators selected before 2013 concluded that the first three most-indicated aspects in different evaluation dimensions are: intelligent infrastructure construction, intelligent governments, and intelligent citizens [28]. In terms of evaluation dimensions, the 38 systems consider the additional dimensions of intelligent industries and an intelligent environment, both of which are highly associated with iCity practices [29].

The approaches applied to the development of an evaluation system are basically implied by the structuring mode of this system. The creation of an indicator system that consists of three integral hierarchies, such as the analytic hierarchy process (AHP) or Delphi method, often employs the regular method of subjective evaluation and a combination of expert seminars. This approach can better utilize expert resources and expertise [30] and can combine qualitative and quantitative factors in the comprehensive consideration [31]. Evaluation systems that do not include evaluation standards, such as grey relational analysis (GRA), principal component analysis (PCA), technique for order preference by similarity to an ideal solution (TOPSIS), and fuzzy comprehensive evaluation (FCE), normally apply an objective evaluation approach, with the purpose of bestowing weights and removing the impacts of indicators that have relatively large relevance [31]. This approach avoids interference from human factors caused by secondary classification or quantization, and directly realizes the transformation from dimensions to indicators and the selection of indicators.

1.2. Deficiencies of current ICESs and some consequences

In addition to experiences drawn from other ICESs, this research also looks into the deficiencies of current systems, which are further classified and analyzed in the four aspects of content setting, approaches, data source of indicators, and evaluation results.

1.2.1. Deficiencies due to ICES developers

The first category of deficiencies frequently occurs in ICESs developed by city governments. Government inventors tend to set up indicators according to the development level and standards of their respective cities. Therefore, such ICESs are created with a poor universality and are incapable of evaluating other cities. The Nangjing System, the Ningbo System, and the Shanghai Pudong System fall into this category.

The second category of deficiencies occurs in ICESs developed by state governments. These state evaluation systems are set up through top-down processes and are adopted to the development status and value orientation of individual countries. Thus, they are not universally applicable and are not well grounded in transnational comparisons [28]. The early-developed Australian System and the Japanese System fall into this category. However, state government ICESs appear to gradually evolve into what this research concludes to be a third category.

The third category of deficiencies is frequently seen in ICESs developed by professional enterprises or professional administrative departments of state governments. ICES developers of this category are usually benefit-oriented and pursue ICES development for their respective agencies. They also tend to incorporate local factors into their indicator systems, resulting in poor universality of these systems. The GMTECH Evaluation System and the China Wisdom Engineering Association (CWEA) System fall into this category.

ICESs developed by academic teams usually portray the development of intelligent cities from a more objective perspective. The City IQ Evaluation System research team has invited 275 experts from 14 high-end research institutes, including the Chinese Academy of Engineering, the National Academy of Science and Engineering (Germany), the Royal Swedish Academy of Engineering Sciences, the Planning Management Center of the Ministry of Housing and Urban-Rural Development (MoHURD) of China, and the Development Research Center of the State Council of China, to participate in the development course of the City IQ Evaluation System in order to ensure impartiality and a scientific approach of the research, which are preconditions of the universal applicability of the City IQ Evaluation System.

1.2.2. Absence of core ideology and deficiencies in dimension setting

In the content setting of current systems, a benefit evaluation and a concern for software are frequently missing. Indicators are often selected to measure inputs rather than the benefit and effectiveness of an iCity [32]. Some software aspects of the construction of intelligent cities are often overlooked as well, such as a concern with human factors [32], a concern with driving forces for the development of intelligent infrastructures from the perspective of users [33], or the use status of public service facilities [34]. In general, the majority of current systems focus more on the objectification of the course while overlooking the core supporting conceptions required by an indicator system. Therefore, in the design of the City IQ Evaluation System, a wider range of factors has been balanced, and responses to both hardware and software aspects are integrated into the City IQ Evaluation System.

1.2.3. Deficiencies in approaches

Both the description of indicator systems by expert groups and the choice of approaches affect the composition of indicator systems [30]. Therefore, although the Delphi and the expert seminar approach are frequently applied to design indicator systems, the evaluation results could be invalid due to a weak influence or authority of the involved experts or assessment institutions [35].

In addition, it is also noted that although the coexistence of quantitative and qualitative indicators could be realized through AHP [31], uncontrollable subjective interference could appear in the process [30]. Therefore, in the development of an ICES, it is critical to combine both qualitative and quantitative approaches [36] as well as taking full advantage of expert resources via an innovative process design.

1.2.4. Deficiencies in indicator selection and data source

Current indicator systems tend to contain deficiencies regarding their data sources and indicator results in the following aspects: First, the same indicators addressing different objects are selected from different data sources [37]; second, the data sources require a relatively long renewal cycle and thus are unfurnished for a dynamic adjustment [36]; third, data from governments tend to be unreliable [37]; and fourth, the authenticity of indicator data that are not firsthand is questionable [38]. In addition, the results of some indicator systems are not relative numbers and therefore provide no comparability [38]. To avoid these deficiencies, this research intensifies the reliability, openness, real-time access, and assessment of indicator data sources; and it is demanded that indicators of the same evaluation item are selected from common sources. The indicator results are displayed in relative numbers to produce results with better comparability and rationality.

2. Conception, research approaches, and development aspects of the City IQ Evaluation System

2.1. Core conception: The intelligent city-being

Many of the ICESs discussed in this research are structured on theories of sustainable development, informatization, and ecologicalization. For example, the Patrizia Lombardi System is structured by the Triple Helix theory of development [1]. Some ICESs are even established without core supporting theories but are composed of indicators describing technological aspects, urban informatization levels, or hardware constructions.

The City IQ Evaluation System research is structured around the critical understanding that an intelligent city evaluation system should be based on the core value, cognition, and theories of the iCity. This means that an evaluation system should address the four circulatory phases of an iCity—sensing, judging, reacting, and learning (Fig. 1)—as required by the philosophy of urban evolution and the value added by the intelligent development of cities [39]. It should also be capable of pushing forward the continuous intelligence course of cities.

- **Comprehensive sensing** refers to the real-time grasping of the demands and changes of individual cities and subjects with the support of sensing, conduction infrastructure, and sufficient data and computing. Urban information is sensed via sensor networks, communication networks, and mobile Internet with the aid of radio-frequency identification (RFID), infrared sensors, and the global positioning system (GPS).
- **Precise judging** on the basis of comprehensive sensing is capable of timely automatic identification, data filtering, calculation, and judgement of any information generated by any changes in a city.
- **Proper reacting** based on precise judging is capable of urban prospect prediction, resource mobilization, plan generation, and realization of the minimal consumption of energy, resource, and time; it can also take social concern into account.
- **Autonomic learning** of an iCity means its reflective learning, sensing, upgrading, and improvement in its decision-making mode and process after the previous three phases. Sustained advancement and intelligence at a higher level is realized via autonomic learning.

Most scholars would probably agree with the idea of intelligent cities as intelligent city-beings are capable of self-organizing, self-adaption, and evolution [40]. Social innovation led by self-organization and learning is the indispensable part of an iCity [2]. Regarding an understanding of the nature of the intelligent city-being and its four significant components, the City IQ Evaluation System research team makes innovations in the principle and approaches of system structuring.

2.2. Innovation in inventing City IQ Evaluation System 1.0

The new system is named the City IQ Evaluation System because it regards an iCity as an intelligent city-being and measures its four components. The first version, City IQ Evaluation System 1.0, was created in 2013. City IQ Evaluation System 2.0 was developed in 2014 after improving the universal applicability, openness, and dynamic data sources of version 1.0. In 2015, City IQ Evaluation System 2.0 was further standardized by applying deviation evaluation methods in assessment results, leading to City IQ Evaluation System 3.0. This part of the paper mainly elaborates on the conception of City IQ Evaluation System 1.0, with a focus on the five steps of primary indicators acquisition, indicator dimensions setting, indicators selection, indicators adjustment, and standardization.

2.2.1. The ring of primary indicators: 220 basic indicators collected from three channels

To include primary indicators in a range that is as wide as possible, the City IQ Evaluation System research team has set up an indicator ring from three channels: experts' advice, indicator bases of other systems, and proposals by the City IQ Evaluation System research team. The City IQ Evaluation System capitalizes on the maximal use of its expert resources: The research team has set up an expert base, inviting 275 experts from 14 high-end research institutes, including the Chinese Academy of Engineering, the National Academy of Science and Engineering (Germany), the Royal Swedish Academy of Engineering Sciences, the Planning Management Center of MoHURD (China), and the Development Research Center of the State Council (China). This expert base thus contributes 121 indicators to "intelligent monitoring over sustainable urban development." A further 135 indicators were selected from indicator bases of other systems, and the research team added another 38 indicators. After summarizing, deduplication, and classification, 220 indicators were finally selected. These are reflected in the primary indicators ring of the City IQ Evaluation System (Fig. 2).

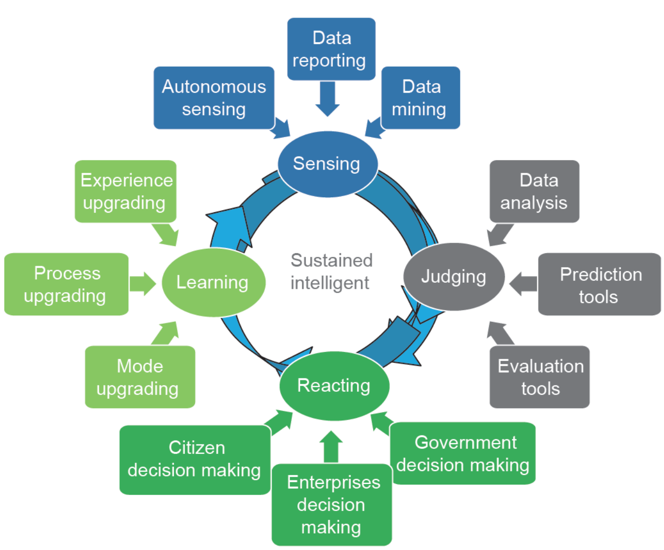

Fig. 1. The core conception of iCity development.

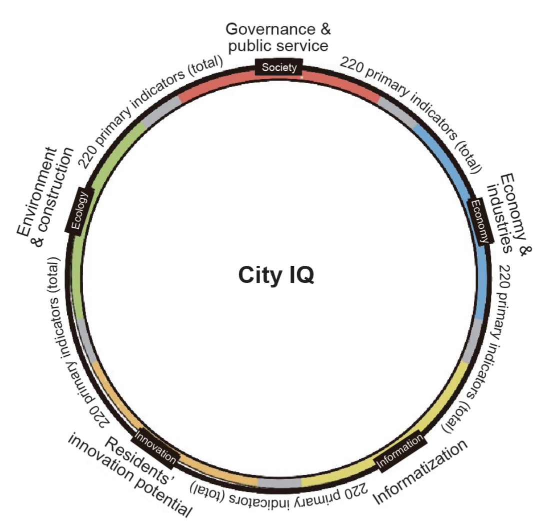

Fig. 2. The primary indicator ring of the City IQ Evaluation System, with 220 indicators.

2.2.2. Five dimensions of the intelligence level of a city

Because this evaluation system regards cities as intelligent city-beings, it is critical to include the manifestation mode suitable for living systems in the indicator dimensions. Traditional measures for the economic, environmental, and industrial performance of a city [28], as well as an assessment of information and communications technology (ICT) hardware construction and the support and interaction generated by human factors [33] should all be considered as reflections of the intelligence level of a city in its course of "sensing, judging, reacting, and learning." Sub-targets concerning urban development environment, future trends, construction operation, and local participation should also be highlighted in the assessment.

After analyzing indicator dimension designs of other systems as well as consulting experts' advice, the City IQ Evaluation System team established 3 + 2 dimensions of its own, see Table 2. Three dimensions assess the environment, economy, and governance of an iCity; namely, the dimensions of environment and construction, governance and public services, and economy and industries. Another two supporting dimensions measure the hardware conditions of an iCity in terms of level of informatization and residents' innovation potential. Fig. 3 illustrates the inner logic among these five dimensions. Output factors and supportive input factors [32] are all included in the measurement of the IQ of a city.

2.2.3. Indicator selection: The principle of measuring intelligence

Indicator selection is another critical process in conceiving the City IQ Evaluation System. Carli [41] regards traditional evaluation indicators as invalid and points out that the evaluation of the IQ of a city could only be realized when the city is "optimally and intelligently measured, monitored, and managed." Some scholars, including De Santis [42], regard the evaluation approaches and the closeness of the dynamic indicator application to local spaces and people as the most critical process in the development of an urban IQ evaluation.

In accordance with the two preconditions required by the principle of selection—deduplication and international applicability—and in order to avoid the deficiencies of the other ICESs as summarized earlier, the City IQ Evaluation System highlights three features of its indicators: common indicators, dynamic adjustment, and open data. Common indicators are collected from open data sources that cover all the data of all cities. Dynamic adjustment requires prompt self-upgrading of data. Open data refers to access to data from third parties via the Internet in order to avoid problems of inaccuracy, incomparability, and intangibility of government data [38]. City IQ has selected 36 evaluation indicators from 220 primary indicators, applying the qualitative approaches of expert seminars and the Delphi method, as well as quantitative approaches by a data association algorithm and a fuzzy evaluation method (Fig. 4).

2.2.4. Indicator adjustment

The City IQ Evaluation System research team has repeatedly conducted experimental assessments using the 36 selected indicators. Assessments were carried out for Pudong (Shanghai), Ningbo, Nanjing, Wuhan, and more. Through the China iCity Construction and Promotion Strategy Research Program, 56 questionnaires were delivered to academicians and experts. Special focus was given to the balancing of the indicators and the content of different dimensions. Finally, 20 indicators, five in each dimension, were selected from the 36 indicators.

2.2.5. Data standardization

A number of ICESs contain both quantitative measurable indicators and indicators that could be turned into quantitative measurements through qualitative judgment [31]. For example, in the WANG Zhenyuan System, level quantization is realized through quantitative judgment [43]. This quantization process of qualitative indicators also exists in the ZHOU Ji DPSIR Model [28], the World Economic Forum System, the MoHURD System, and the Ministry of Industry and Information Technology (MIIT) System. A few indicators of the City IQ Evaluation System are also processed by this approach. For example, score 100 in the indicator "reacting to emergencies" indicates countermeasures for reacting to emergencies, such as emergency reporting systems on municipal governments' websites, an emergency plan, and instant guidance in emergencies; score 50 indicates that countermeasures

Table 2
Dimensions and indicators of City IQ Evaluation System 1.0.

Dimensions	Indicators	Unit
Environment and construction	Housing area for urban residents per capita	m^2
	Built area	km^2
	Residential land	m^2 per capita
	Industrial land	m^2 per capita
	Green land	m^2 per capita
	Water pollution index	–
	Water energy per capita	m^3 per capita
	Cultivated land per capita	hm^2 per capita
	Construction land per capita	m^2 per capita
	Natural ecological land coverage	%
	Water supply popularization	%
	Wastewater treatment ratio	%
	Road-hardening ratio	%
	Clean energy popularization	%
	Waste-collection ratio	%
Governance and public service	Rural migrant workers pension insurance ratio	%
	Rural migrant workers employment insurance ratio	%
	Labor dispute settlement rate	%
	Petition events junction rate	%
Economy and industries	Gross domestic product (GDP)	million CNY
	Urban labor productivity	CNY
	Urban output value	thousand CNY
	Tertiary industry output/GDP	%
	Secondary industry output/GDP	%
	Land price	$CNY·m^{-2}$
Level of informationization	Data Internet popular	%
Residents' innovation potential	Net migration ratio	%
	Total migration ratio	%
	Demographic structure impact index	–
	Social impact index	–
	Resource environment impact index	–
	Public service impact index	–
	Labor market employment ratio	%
	Urban-rural income gap	thousand CNY
	Non-rural population in employed population	%
	Energy consumption per capita	standard coal (ton) per capita

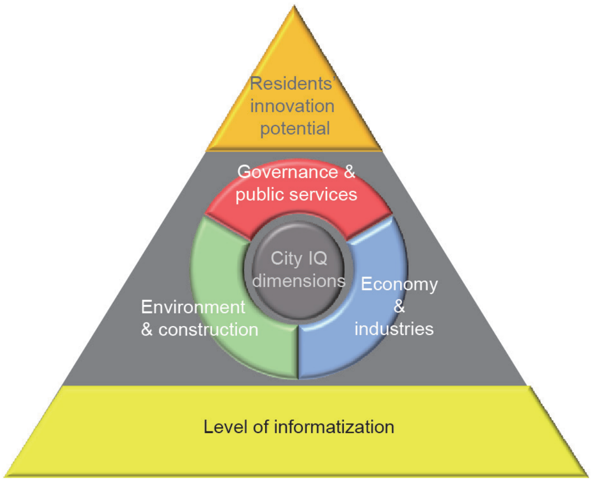

Fig. 3. Inner logic of five indicator dimensions of the City IQ Evaluation System.

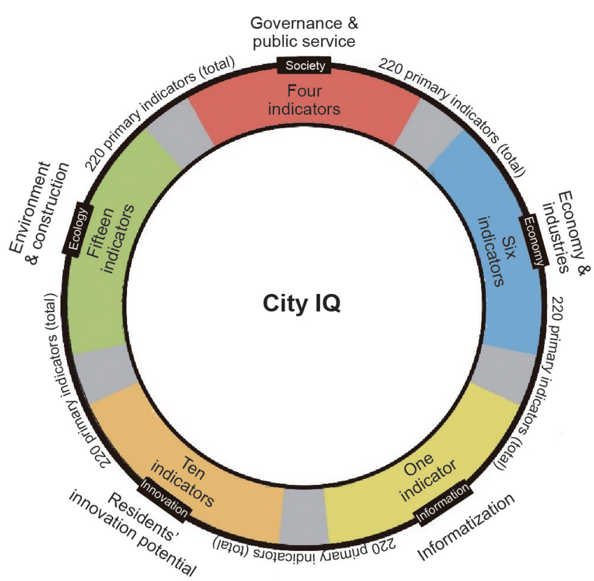

Fig. 4. The City IQ Evaluation System framework with 36 selected indicators.

to emergencies exist, but without recorded details, or that only some regions in the city have such emergency countermeasures; while score 0 means no emergency countermeasures at all.

In order to realize the standardized application of quantitative indicators and qualitative indicators that can be quantified, and to eliminate the impacts among different dimensions, the City IQ Evaluation System employs a score scale from 0 to 100, which is more in line with common evaluation practices and which provides higher comparability, as 0–100 scores can reflect the performance of different cities on the same indicator [38].

The data standardization categories are listed below. The City IQ Evaluation System applies the format of the second category: The city that has been given the highest score, 100, by the City IQ Evaluation System is set as the criteria city, and the other cities are evaluated with scores ranging from 0 to 100 according to the standardized value of the sample city. This data standardization approach is the choice after repeated evaluations.

Category 1: $A_i' = (A_i - A_{\min})/(A_{\max} - A_{\min})$

Category 2: $A_i' = A_i/A_{\max}$

Category 3: $A_i' = (A_i - \bar{A})/\sigma_i$, when $\sigma_i^2 = \sum(A_i - \bar{A})^2/n$

After data standardization of 20 indicators, different city performances regarding different indicators displayed scores from 0 to 100. The score a city gets for one dimension is the average value of all indicator scores under this dimension. The total score of a city's intelligence performance is defined as the average value of its scores across five dimensions. The detailed standardization process and calculation are shown in Table 3. In this calculation process, the average value is applied to obtain the dimension scores from indicator scores and the comprehensive total score from dimension scores. The reason for this method is that in designing the indicator system, the balance between different dimensions and indicators is profoundly considered, and the reverse effect caused by repeated weighting and the incomparability of results is avoided as much as possible.

3. City IQ Evaluation System 2.0: Improvements toward better universal applicability, openness, and dynamic data sources

3.1. City IQ Evaluation System 2.0 and its data source adjustment

City IQ Evaluation System 1.0 was created with joint support from multiple academic teams and experts, and the basic version of the City IQ Evaluation System was formed after indicator selection and adjustment. The indicator selection and approaches applied to this 36-indicator system are rationally designed.

However, first evaluations showed that some indicators lack data sources or quality data. There is still a long way to go to achieve the intended goals of globally applicable, dynamic, and open evaluations of the intelligence of cities. Therefore, the City IQ Evaluation System research team created further definitions, simplifications, and amendments to the 36 existing indicators after combining the status of data quality, pre-assessment results, and the second round of expert feedback, and extracted 20 from the 36 indicators (as shown in Table 4).

All 20 indicators meet three significant preconditions: globally applicable data, open data without governmental interference, and real-time and dynamically adjustable data. They include both qualitative measurable indicators and quantitative measurable indicators [36].

Compared with traditional indicators, these 20 indicators describe a more innovative approach to measuring the intelligence of a city, as they reflect the sensing, judging, reacting, and learning processes of a city in a more realistic and timely way. For example, the indicator "density of city PM2.5/PM10 monitoring stations" reflects a city's capacity to sense air elements, and its performance in judging and reacting to the urban agenda of environmental changes. The indicator "online public participation ratio" reflects the patency of the pathway along which public requests can reach decision makers and how public requests can affect decision making. In this way, this indicator reflects a city's sensitivity and intelligence in "sensing" its citizens' will.

Finally, City IQ Evaluation System 2.0 is established on five dimensions and 20 indicators. Fig. 5 illustrates the full content of City IQ Evaluation System 2.0. The outer sphere, middle layer, and inner layer of the ring reflect the 220 primary indicators, 35 selected indicators, and 20 finalized indicators, respectively, with the City IQ Evaluation System as the core that is split into five dimensions. Table 4 illustrates the specific content of the 20 indicators assigned to the five dimensions.

3.2. City IQ Evaluation System 2.0: Evaluation results of global intelligent cities

To evaluate the global applicability of City IQ Evaluation System 2.0, the research team selected the top eight out of 33

Table 3
Data standardization and indicator calculation.

No.	Cities	Total scores	Environment & construction					Governance & public service					Economy & industries					Informatization					Innovative human resource				
			Density of city PM2.5/PM10 monitoring stations	Urban grid management coverage	Ratio of citizens using Intelligent transportation citizen use ratio	Online openness of future city construction plans	Scores of dimension	Online openness of non-confidential governmental documents	Online public participation ratio	Level of citizen using e-health recording	Emergency reacting performance	Scores of dimension	R&D expense/GDP	Urban productivity	Urban production value density	Urban intelligent industry ratio	Scores of dimension	Free WiFi coverage in public space	Average mobile network access	Building automatic system popularization	Intelligent grid coverage	Scores of dimension	Urban netizen ratio	IT professionals ratio	Population ratio with college education	Expense of e-purchase per capita	Scores of dimension
1	Ningbo	54.66	21.65	44.36	100	100	66.50	52.75	56.07	50	100	39.96	32.87	76.46	60.48	13.77	45.89	100	33.33	100	100	83.33	23.94	6.99	42.60	75	37.13
2	Wuhan	46.30	9.97	19.26	100	0	32.31	53.84	29.12	50	100	54.24	26.79	22.49	36.61	25.29	27.79	17	100.00	50	100	62.54	17.85	9.70	100.00	75	50.64
3	Wenzhou	45.88	38.37	27.29	50	100	53.92	46.65	1.28	50	100	49.48	16.87	66.33	51.75	13.77	37.18	85	37.50	100	0	34.59	100.00	6.05	35.87	75	54.23
4	Zhuhai	44.83	18.14	14.80	100	100	58.23	95.42	5.97	100	100	75.35	51.43	38.01	32.68	18.11	35.06	20	25.00	0	0	6.30	26.01	26.58	69.20	75	49.20
5	Taizhou	40.59	100.00	31.94	50	100	70.49	41.70	68.49	50	0	40.05	15.11	80.84	100.00	59.87	63.95	34	4.17	0	0	1.13	11.34	10.59	37.34	50	27.32
6	Wuxi	39.02	13.58	31.24	100	100	61.21	50.73	56.19	50	0	39.23	30.90	80.60	66.95	59.87	59.58	22	29.17	0	0	7.35	25.77	6.63	28.47	50	27.72
7	Dezhou	38.22	47.39	35.44	100	0	45.71	44.22	100.00	50	100	73.55	0.92	93.96	80.49	17.79	48.29	1	8.33	0	0	2.09	9.82	6.79	44.33	25	21.48
8	Zhuzhou	37.85	27.94	7.42	50	100	46.34	30.74	8.14	100	100	59.72	23.78	45.84	35.56	100.00	51.30	10	8.33	0	0	2.11	8.27	9.37	51.59	50	29.81
9	Dongying	37.65	51.46	26.16	100	0	44.40	32.23	11.00	50	100	48.31	7.27	94.41	72.80	17.79	48.07	1	8.33	50	0	14.58	22.17	19.29	40.08	50	32.89
10	Weihai	37.26	24.93	15.11	100	100	60.01	36.90	43.61	0	100	45.13	15.97	100.00	48.43	17.79	45.55	4	12.50	0	0	3.13	20.07	3.48	56.32	50	32.47
11	Jinhua	37.11	53.24	100.00	100	100	88.31	41.17	4.05	0	0	11.30	10.90	75.04	95.49	13.77	48.80	96	16.67	0	0	4.41	22.50	17.76	40.63	50	32.72
12	Wuhu	36.19	15.42	10.98	100	100	56.60	88.65	1.49	50	0	35.04	100.00	28.49	24.95	44.08	49.38	39	12.50	0	0	3.22	10.50	3.57	82.79	50	36.72
13	Changzhou	35.95	16.20	30.67	100	100	61.72	37.08	0.11	0	100	34.30	25.34	43.57	57.78	59.87	46.64	42	16.67	0	0	4.27	35.84	6.85	38.71	50	32.85
14	Langfang	34.79	83.29	34.71	100	100	79.50	32.82	3.17	50	0	21.50	7.20	53.83	72.11	13.79	36.64	7	8.33	0	0	2.10	18.92	15.62	51.92	50	34.12
15	Zhenjiang	34.64	19.66	17.78	100	100	59.36	49.81	23.77	50	0	30.89	14.82	63.25	57.63	59.87	48.89	24	8.33	0	0	2.14	15.07	3.99	58.57	50	31.91
16	Ya'an	33.59	0	15.25	0	100	28.81	8.79	5.46	100	100	53.56	2.34	30.91	51.22	25.33	27.45	15	4.17	0	0	1.08	4.54	100.00	98.65	25	57.05
17	Qinhuangdao	33.27	54.79	16.26	100	100	67.76	41.98	53.04	50	0	36.26	8.20	35.75	33.94	13.79	22.92	3	4.17	0	0	1.05	22.61	6.12	74.68	50	38.35
18	Tongling	31.66	0	5.35	50	100	38.84	50.77	12.65	50	100	53.36	24.11	34.83	25.36	44.08	32.10	20	4.17	0	0	1.09	13.22	4.98	38.40	75	32.90
19	Xianyang	29.57	33.51	20.47	100	100	63.49	52.65	0	0	0	13.16	4.08	39.33	55.17	12.23	27.70	30	8.33	0	0	2.16	10.43	9.10	70.74	75	41.32
20	Handan	29.20	43.17	19.69	100	100	65.71	29.30	3.03	50	0	20.58	4.78	41.11	66.12	13.79	31.45	1	8.33	0	0	2.09	20.10	6.52	28.11	50	26.18
21	Changzhi	27.71	28.37	21.43	0	100	37.45	100.00	5.18	0	100	51.30	8.89	42.19	52.17	6.70	27.49	3	8.33	0	0	2.09	13.18	12.32	30.42	25	20.23
22	Nanping	26.08	0	16.54	0	100	29.14	43.66	1.09	0	100	36.19	7.13	49.01	86.73	17.90	40.19	23	8.33	0	0	2.68	19.36	35.06	9.41	25	22.21
23	Hebi	23.93	0	11.45	0	100	27.86	42.91	33.25	50	100	56.54	7.58	22.45	24.16	29.67	20.97	1	4.17	0	0	1.05	15.01	2.92	10.04	25	13.24
24	Bengbu	23.60	0	11.71	100	100	52.93	44.25	0.20	0	0	11.11	51.46	21.73	18.59	44.08	33.96	48	4.17	0	0	1.16	8.98	3.11	38.27	25	18.84
25	Luohe	22.53	0	18.21	100	100	54.55	23.44	6.88	50	0	20.08	5.63	16.61	38.21	29.67	22.53	1	4.17	0	0	1.04	13.94	6.58	11.99	25	14.38
26	Huainan	21.98	0	5.43	50	100	38.86	74.17	3.12	50	0	31.82	18.95	11.17	20.90	44.08	23.78	47	4.17	0	0	1.16	6.36	2.74	23.11	25	14.30
27	Wuhai	20.09	0	11.54	0	100	27.88	5.86	0.22	50	100	39.02	23.68	29.64	20.78	6.96	20.26	1	4.17	0	0	1.04	10.34	8.26	5.36	25	12.24
28	Pingxiang	18.65	0	14.38	0	100	28.60	54.61	8.66	0	0	15.82	7.65	19.92	40.40	60.49	32.12	3	4.17	0	0	1.05	19.69	10.31	7.73	25	15.68
29	Liupanshui	16.44	0	9.24	0	0	2.31	37.65	0.03	50	100	46.92	6.85	33.75	43.71	13.15	24.36	5	4.17	0	0	1.06	8.79	11.76	9.73	0	7.57
30	Liaoyuan	13.70	0	7.14	0	100	26.79	23.44	3.82	0	0	6.82	7.78	27.71	29.74	9.92	18.79	2	20.83	0	0	5.21	6.00	0.98	11.52	25	10.88
31	Lhasa	11.66	35.68	17.26	0	0	13.23	8.79	42.12	0	0	12.73	0	26.66	9.56	5.38	10.40	24	4.17	0	0	1.10	0	41.72	16.53	25	20.81

Table 4
Dimensions and indicators of City IQ Evaluation System 2.0.

Dimension	Indicator	Unit
Environment & construction	Density of city PM2.5/PM10 monitoring stations	stations·km^{-2}
	Urban grid management coverage	%
	Intelligent transportation citizen use ratio	%
	Online openness of future city construction plan	%
Governance & public service	Online openness of non-confidential governmental documents	%
	Online public participation ratio	%
	Level of citizen using e-health recording	%
	Emergency reacting performance	%
Economy & industries	R&D expense/GDP	%
	Urban productivity	thousand CNY
	Urban production value density	thousand CNY·km^{-2}
	Urban intelligent industry ratio	%
Informatization	Free WiFi coverage in public space	%
	Average mobile network access	%
	Building automatic system popularization	%
	Intelligent grid coverage	%
Innovative human resource	Urban netizen ratio	%
	IT professionals ratio	%
	Population ratio with college education	%
	Expense of e-purchase per capita	CNY

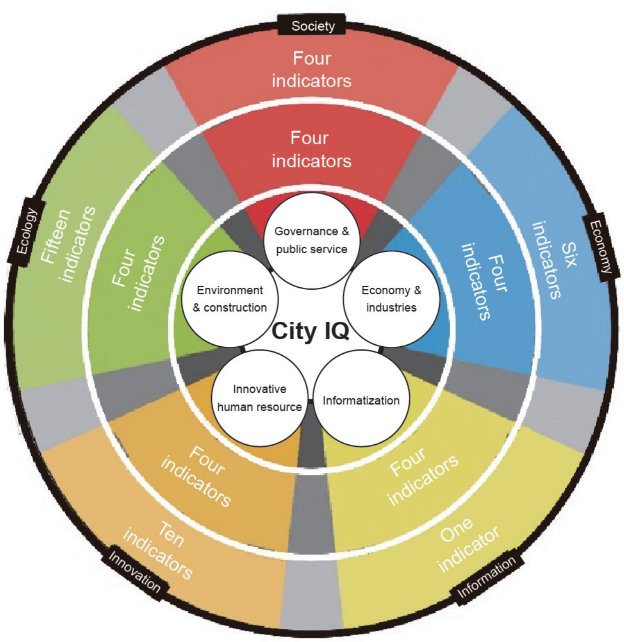

Fig. 5. City IQ Evaluation System 2.0 dimensions and indicators.

Chinese cities evaluated by City IQ Evaluation System 2.0, and another 33 cities from Europe and the US, and conducted a new round of intelligence evaluation on these 41 sample cities. The newly selected 33 European and the US cities are those that had promoted iCity construction concepts worldwide and that had implemented iCity construction practices for a long time. Table 5 shows City IQ Evaluation System 2.0 evaluation results for the 41 cities. Fig. 6 shows the intelligence performances of nine selected cities, whose dimension scores and indicator scores are visually illustrated by the City IQ Evaluation System 2.0 score compass.

3.2.1. City IQ Evaluation System 2.0 evaluation results

The following is the evaluation results of 41 cities in China and other countries by City IQ Evaluation System 2.0 (Table 5, Fig. 6).

3.2.2. City IQ Evaluation System 2.0: Analysis of evaluation results

Among the intelligence evaluation results of 41 global cities, London scored the highest at 66, which amounts to roughly 2.5 times the lowest score, 26 for Verona, Italy. This result illustrates the global applicability and sensitivity of City IQ Evaluation System 2.0. In general, the gaps between cities are not as wide as expected, indicating that the 41 selected cities are actually typical cases of iCity practices around the world.

Cities with average comprehensive scores over 60 include London, Amsterdam, and Helsinki, among others; these cities have obvious resource superiority in their respective countries and are recognized as global city-regions or metropolitan areas [44]. In contrast, Verona, Santander, Málaga, Friedrichshafen, and other cities that scored below 40 are cities that assign priority to one development aspect rather than to overall development. For example, Friedrichshafen adopts a development mode that is oriented toward Deutsche Telekom, with governmental partnership to promote ICT applications and develop a knowledge city [22], while losing sight of other development aspects. For this reason, Friedrichshafen receives a relatively low score.

In the dimension of "environment and construction," Amsterdam ranks first with 98, about eight times the lowest score, which was 13 for Verona. The evaluation of this dimension displays a three-level city echelon: 22 top cities scored above 70, 12 middle cities scored between 40–69 , and seven at the bottom scored below 40.

In the dimension of "governance and public service," Helsinki ranks first with 75, four times the lowest score, which was 18 for Málaga. Cities ranking high in governance and public services are important political, economic, and cultural centers of their respective countries; Boston, Amsterdam, London, and Shanghai Pudong all scored above 70. In contrast, cities such as Jinhua, Cologne, and Lyon score below 40 because of poor intelligence per-

Table 5
City IQ Evaluation System 2.0 evaluation results of 41 global cities.

Cities	Total score		Environment & construction		Governance & public service		Economy & industries		Informatization		Innovative human resource	
	Rank	Score	Rank	Score	Rank	Score	Rank	Score	Rank	Score	Rank	Score
London	1	66	13	78	4	72	6	53	4	63	5	62
Amsterdam	2	66	1	98	3	73	5	54	10	57	27	46
Helsinki	3	64	10	85	1	75	8	48	23	48	3	65
Boston	4	64	6	88	2	74	3	60	31	41	14	56
Copenhagen	5	63	8	86	27	51	4	60	5	63	13	56
Vienna	6	61	4	92	15	69	22	36	7	61	25	48
Washington, DC	7	61	24	68	19	62	1	76	24	46	23	54
Seattle	8	60	2	92	33	46	9	47	9	60	18	55
Chicago	9	59	18	76	13	70	17	42	17	52	17	55
San José	10	59	14	77	11	70	24	35	14	54	8	59
Portland	11	58	23	69	10	70	20	39	12	55	10	57
San Diego	12	57	17	76	5	72	28	33	21	50	19	55
Dubuque	13	57	26	63	8	71	34	27	18	50	1	72
Manchester	14	56	12	82	28	48	7	52	36	35	4	64
New York	15	56	22	72	32	46	14	44	8	61	22	55
Barcelona	16	55	20	75	26	54	10	47	2	69	28	32
Detroit	17	53	34	45	12	70	18	41	19	50	11	56
Minneapolis-Saint Paul	18	52	27	63	20	60	15	44	35	39	15	56
Philadelphia	19	52	15	76	31	46	16	43	33	40	21	55
Ningbo	20	52	7	87	6	72	37	23	3	65	37	13
Issy-les-Moulineaux	21	51	38	25	23	58	30	31	1	71	2	72
San Francisco	22	51	25	67	30	47	13	45	32	41	20	55
Lisbon	23	50	28	63	16	67	29	32	6	62	34	24
Cleveland	24	48	35	38	21	59	19	41	20	50	16	55
Birmingham	25	47	37	28	7	71	12	46	40	33	6	60
Århus	26	47	29	63	38	25	11	46	26	45	9	58
Liverpool	27	47	40	20	22	58	2	61	37	34	7	60
Wuhan	28	46	11	82	14	69	35	27	30	42	41	11
Wuxi	29	46	9	85	17	63	23	35	38	33	38	13
Turin	30	45	31	50	18	62	27	34	13	54	32	27
Zhenjiang	31	45	5	90	29	47	25	35	29	43	39	12
Shanghai Pudong	32	45	19	76	9	71	40	19	25	45	35	14
Jinhua	33	45	3	92	35	33	36	26	34	40	29	32
Taizhou	34	43	21	75	24	58	21	37	39	33	36	14
Cologne	35	43	32	50	40	22	26	34	15	53	12	56
Zhuhai	36	42	16	76	25	57	38	22	28	43	40	12
Lyon	37	42	30	53	36	32	33	29	22	48	26	46
Friedrichshafen	38	36	39	25	34	34	32	29	27	43	24	50
Málaga	39	35	36	38	41	18	31	31	11	56	30	32
Santander	40	32	33	50	37	29	39	22	41	31	31	30
Verona	41	26	41	13	39	24	41	12	16	53	33	27

Based on City IQ Evaluation System 2.0 intelligence evaluation results, 2013.

formance in the field of public service.

In the dimension of "economy and industries," Washington, DC ranks first with 76, more than six times the lowest score, which was 12 for Verona. There are wide gaps between other evaluated cities as well in the field of intelligent economy and industries.

In the dimension of "informatization," Issy-les-Moulineaux of Paris ranks first with a score of 71, which is 2.3 times the lowest score of 31 for Santander, Spain. Capital cities rank among the top cities, and some Chinese cities, such as Ningbo, Wuxi, Zhenjiang, and Shanghai Pudong, also received high scores because these intelligent cities have all invested heavily in hardware facilities and seen significant results.

In the dimension of "innovative human resource," Dubuque, USA, ranks the highest with a score of 72, almost 6.55 times the lowest score of 11 for Wuhan, Hubei, China. With the impact of indicators such as IT professionals ration, population ratio with college education, and citizen e-purchase expense per capita, Chinese cities with resource priority could not perform best in

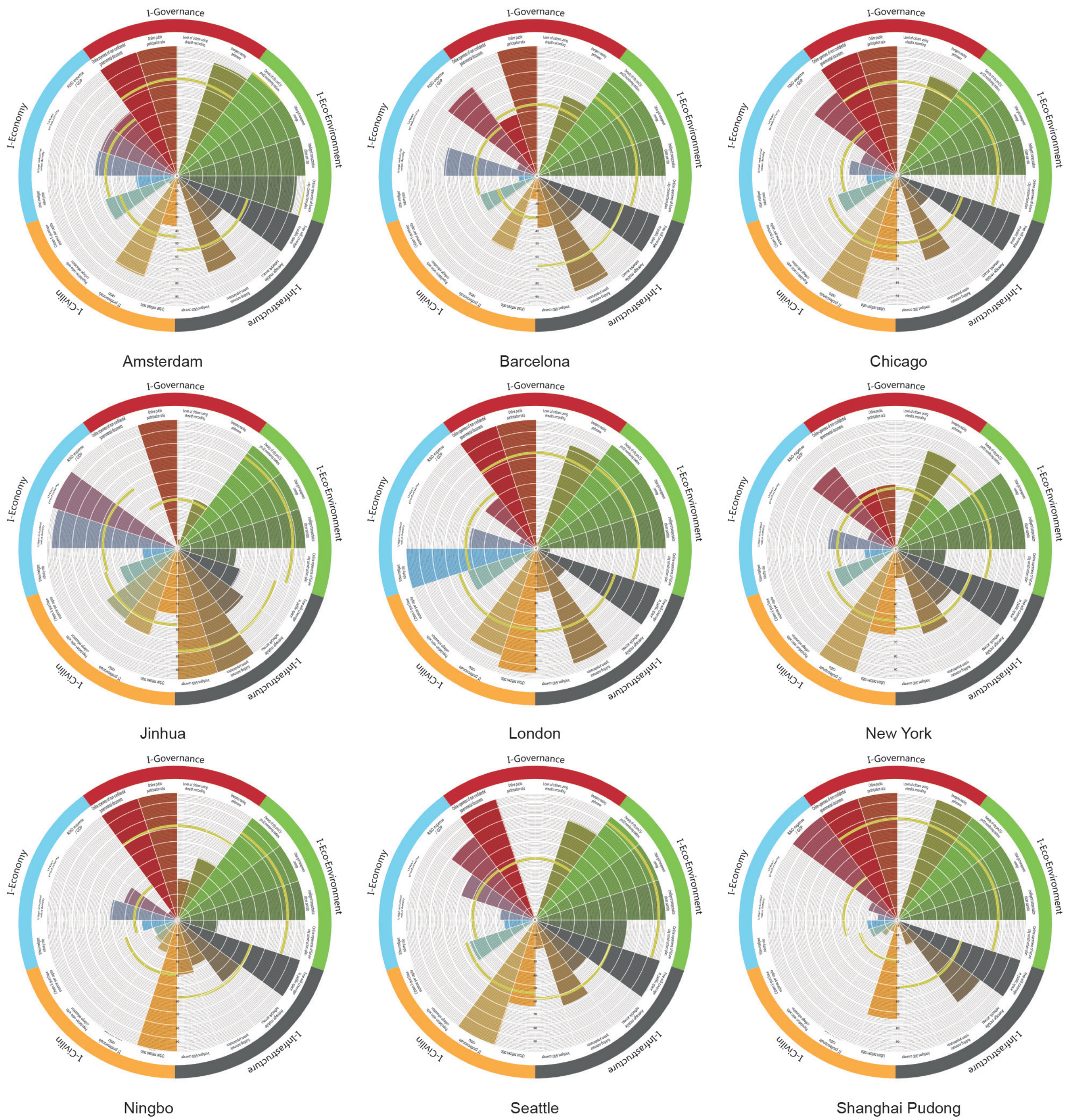

Fig. 6. City IQ Evaluation System 2.0 intelligence score compass.

this aspect. There are also large gaps between global cities in this dimension.

4. City IQ Evaluation System 3.0: The IQ evaluation-oriented version

4.1. City IQ Evaluation System 3.0: Introduction of IQ deviation evaluation methods

Judging from the evaluation results of 41 iCities around the world, City IQ Evaluation System 2.0 exhibits higher sensitivity than version 1.0. Its data resource contributes to the characteristics of pervasiveness, openness, and real-time dynamics, constituting a theoretical and methodological innovation from traditional city intelligent quotient evaluation systems.

City IQ 2.0 realizes real-time dynamics of data evaluation; however, its results cannot reflect an integrated development level of city intelligence, indicating the gap between IQ evaluation theory and its outcome. It cannot reflect the overall rising trends of a city's intelligent level, known as the "Flynn effect" [46], as the overt IQ trend for the human species.

To address this deficiency of City IQ Evaluation System 2.0, which was issued in 2014, the City IQ Evaluation System research team introduced IQ evaluation theory and a data standardization process into the system in 2015, in order to approach the original goal of measuring a city's intelligence growth as a city-being. The improved version, City IQ Evaluation System 3.0, has been under development since 2015. Like 2.0 version, City IQ Evaluation System 3.0 adopts the hundred score system; however, it includes an IQ deviation evaluation method (IQ EDM) in order to normalize the mean value of various indicators as 100 points (Fig. 7); namely, $A_i' = A_i/A_{mean}$. This is unlike the ratio IQ indicator system of City IQ Evaluation System 2.0, which assigns the value 100 to the maximum sample ratio IQ.

The corresponding results are more consistent with IQ evaluation principles and performance features, and objectively reflect the intelligence level of sample cities in city clusters.

4.2. Evaluation results of global intelligent cities by City IQ Evaluation System 3.0

Using City IQ Evaluation System 3.0, the research team has carried out a new round of city IQ evaluations for the selected 41 global cities that were evaluated using City IQ Evaluation System 2.0. Table 6 shows the result, and Fig. 8 shows the score compasses for the extracted nine cities. Comparing Table 6 with Table 5, the nominal score of 100 points has been adjusted from the maximum value (as shown in Table 5) to the mean value (as shown in Table 6), and some scores exceed 100 in different dimensions in both Table 6 and Fig. 8.

4.2.1. Evaluation result by City IQ Evaluation System 3.0

The following is the evaluation results by City IQ Evlauation System 3.0 of 41 cities in China and other countries (Table 6, Fig. 8).

4.2.2. Result analysis of City IQ Evaluation System 3.0

Compared with the evaluation results of 41 global iCities using City IQ Evaluation System 2.0 in 2014, the results of the same 41 cities calculated using City IQ Evaluation System 3.0 in 2015 are as follows.

Firstly, the evaluation results from City IQ Evaluation System 3.0 and City IQ Evaluation System 2.0 are considerably stable. The rankings fluctuate slightly in smaller spheres of cities, with an obvious rise of ten rankings for Taizhou. Washington, DC has moved up five rankings, and Wuxi has moved up four rankings. Issy-les-Moulineaux has decreased five rankings, and Jinhua has decreased two rankings. London remains at the top, and the last six cities remain in the same rankings.

Secondly, compared with the rest of the 41 global iCities, Chinese cities remain at the lower level from their mean value in five dimensions while displaying a distinct deviation on certain indicators, which presents an uneven development trend in the five dimensions. Cities in Europe and the US remain at a mean level in the five dimensions, and present even development trends. As the red lines show in Fig. 9, the mean value of each score compass is 100.

Thirdly, these 41 cities retain an outstanding performance in aspects of intelligent urban management and service, and intelligent urban construction and environment, but present insufficient performance in residents' intelligence innovation potential, intelligent economics, and industries.

The results reflect the development of various cities in terms of iCity construction and iCity management over one year, as well as the relative decline of slow-progressing cities in certain dimensions. After data normalization, a score of 100 was reassigned from the maximum sample value to the mean value; as a result, the score highlights cities above average level more directly.

The results further demonstrate the superiority of City IQ Evaluation System 3.0 over City IQ Evaluation System 2.0, in that the former more clearly indicates a city IQ level compared with a mean score, while the sensitivity of the system remains unchanged.

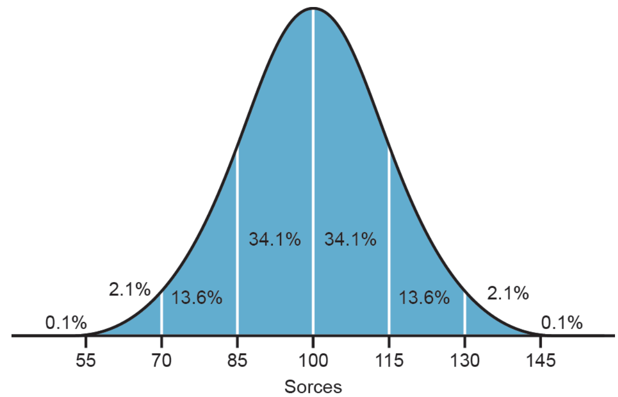

Fig. 7. Normalized distribution of IQ with a mean of 100 and a standard deviation of 15. Source: Ref. [2].

4.2.3. Analysis of city intelligence growth and development

The five dimensions of City IQ Evaluation System 3.0 can be classified as the hardware or software on which a city's IQ depends. Building environment, economic industry, and hardware infrastructure are preconditions of intelligent hardware, and management and service as well as urban labor potential are two preconditions of intelligent software. The City IQ Evaluation System research team reviewed the intelligence evaluation results of the selected 41 global cities and allotted them into the coordinate axes of intelligent developing hardware and intelligent growing software, with a score of 100 as the boundary of high growth and low growth (as shown in Fig. 9).

Quadrant 1 (bottom left): lower development level of intelligent hardware and software. The development level of intelligent hardware and software is rather low in this quadrant, which includes most Chinese iCities, and parts of European iCities. Most cities in this stage may have chosen to operate from only one aspect of iCities, and are in a first stage of changing from theory into real practice.

Quadrant 2 (bottom right): high hardware level, low software level. Intelligent hardware possesses a higher growth level, and software possesses a lower growth level. Most Chinese cities fall into this quadrant, which reflects a large short-term investment and achievement in intelligent infrastructures. However, intelligent management and service and public accomplishment could not be improved over such a short period of time.

Quadrant 3 (up left): low-level growth of hardware and high-level growth of software. The development level of intelligent hardware is low compared with a higher development level of intelligent software. The city invests more in intelligent public service infrastructure, such as management, business, and education, prior to intelligent hardware construction.

Quadrant 4 (up right): high-level growth and development of both intelligent hardware and software. Cities in this quadrant embody not only effectiveness of construction investment in intelligent infrastructure, but also prowess in intelligent software, which could not be realized through city construction, policy stimulation, and investment in a short time.

5. Conclusions

By an analysis of 38 existing ICESs worldwide, this research reveals that current ICESs are not fully trustable because of their common lack of global comparability. The data sources of these ICESs are under the influence of the statistical systems of individual countries. To avoid this non-objectivity, the City IQ Eval-

Table 6
Evaluation results of 41 global cities by City IQ Evaluation System 3.0.

Cities	Total score		Environment & construction		Governance & public service		Economy & industries		Informatization		Innovative human resource	
	Rank	Score	Rank	Score	Rank	Score	Rank	Score	Rank	Score	Rank	Score
London	1	130	13	118	5	129	6	137	4	133	5	139
Washington, DC	2	129	24	103	20	110	1	194	1	146	23	121
Helsinki	3	129	10	129	2	134	8	122	16	112	3	146
Amsterdam	4	128	1	148	4	131	5	139	19	108	27	103
Boston	5	128	6	134	3	133	3	153	24	89	14	125
Copenhagen	6	122	8	130	27	91	4	153	8	120	13	125
Vienna	7	119	4	140	16	124	22	92	9	119	25	108
Seattle	8	118	2	140	33	82	9	121	7	121	18	124
Chicago	9	118	18	115	14	126	17	109	13	115	17	124
San José	10	115	14	117	12	126	24	89	20	106	8	131
Portland	11	115	23	104	11	126	20	100	11	118	10	128
San Diego	12	113	17	115	6	128	28	85	21	104	19	123
Dubuque	13	111	26	95	9	127	34	70	23	101	1	161
Manchester	14	111	12	125	28	86	7	134	37	69	4	142
New York	15	110	22	109	32	82	14	113	5	133	22	122
Barcelona	16	107	20	114	26	96	10	120	2	138	28	72
Detroit	17	104	34	68	13	126	18	106	22	104	11	127
Minneapolis-Saint Paul	18	104	27	95	21	107	15	112	32	82	15	125
Philadelphia	19	103	15	116	31	83	16	111	30	83	21	122
Ningbo	20	102	7	132	7	128	37	58	3	137	37	30
San Francisco	21	101	25	101	30	84	13	116	31	83	20	123
Cleveland	22	97	35	57	22	106	19	104	15	112	16	124
Lisbon	23	96	28	95	17	120	29	82	6	123	34	53
Taizhou	24	94	21	114	1	148	21	95	39	60	36	30
Wuxi	25	94	9	129	18	113	23	91	25	88	38	28
Issy-les-Moulineaux	26	94	38	38	24	104	30	79	18	108	2	160
Birmingham	27	93	37	43	8	128	12	117	40	60	6	134
Århus	28	91	29	95	37	45	11	118	33	82	9	131
Liverpool	29	91	40	30	23	105	2	157	38	62	7	133
Wuhan	30	91	11	125	15	124	35	69	29	84	41	24
Turin	31	90	31	76	19	111	27	87	10	119	32	61
Zhenjiang	32	89	5	136	29	85	25	89	26	87	39	27
Shanghai Pudong	33	87	19	115	10	126	40	50	27	86	35	32
Cologne	34	84	32	76	39	39	26	88	17	109	12	126
Jinhua	35	82	3	140	40	38	36	68	35	77	29	71
Zhuhai	36	82	16	115	25	102	38	57	28	84	40	27
Lyon	37	77	30	81	35	57	33	75	36	70	26	104
Friedrichshafen	38	70	39	38	34	61	32	75	34	80	24	113
Málaga	39	67	36	57	41	33	31	79	14	113	30	71
Santander	40	63	33	76	36	52	39	56	41	59	31	68
Verona	41	51	41	19	38	44	41	31	12	117	33	61

Based on City IQ Evaluation System 3.0 evaluation results, 2015.

uation System research applied common indicators drawn from open data sources and realized real-time updating to address fast changes in cities. Thus, results from the City IQ Evaluation System are globally comparable and trustable.

(1) Intelligent living city theory. ICESs should be derived from a theory of intelligent cities. The City IQ Evaluation System research team applies the theory of intelligent living cities as the core concept of the system. In this theory, intelligent cities are seen as dynamic living city-beings that can sustainably grow in aspects of sensing, judging, reacting, and learning. Compared with traditional indicator systems that are based on sustainable development theory or informatization theory, or systems that are derived from technological aspects only, the City IQ Evaluation System is innovative, comprehensive, and reliable.

(2) Universally applicable, open, and dynamic data sources. City IQ Evaluation System 1.0 meets the basic requirements of an intelligent city evaluation system and has a profound scientific basis. On this basis, City IQ Evaluation System 2.0 adjusted its indicator source from traditional data sources to a system that features better global applicability, online open data, and timely and

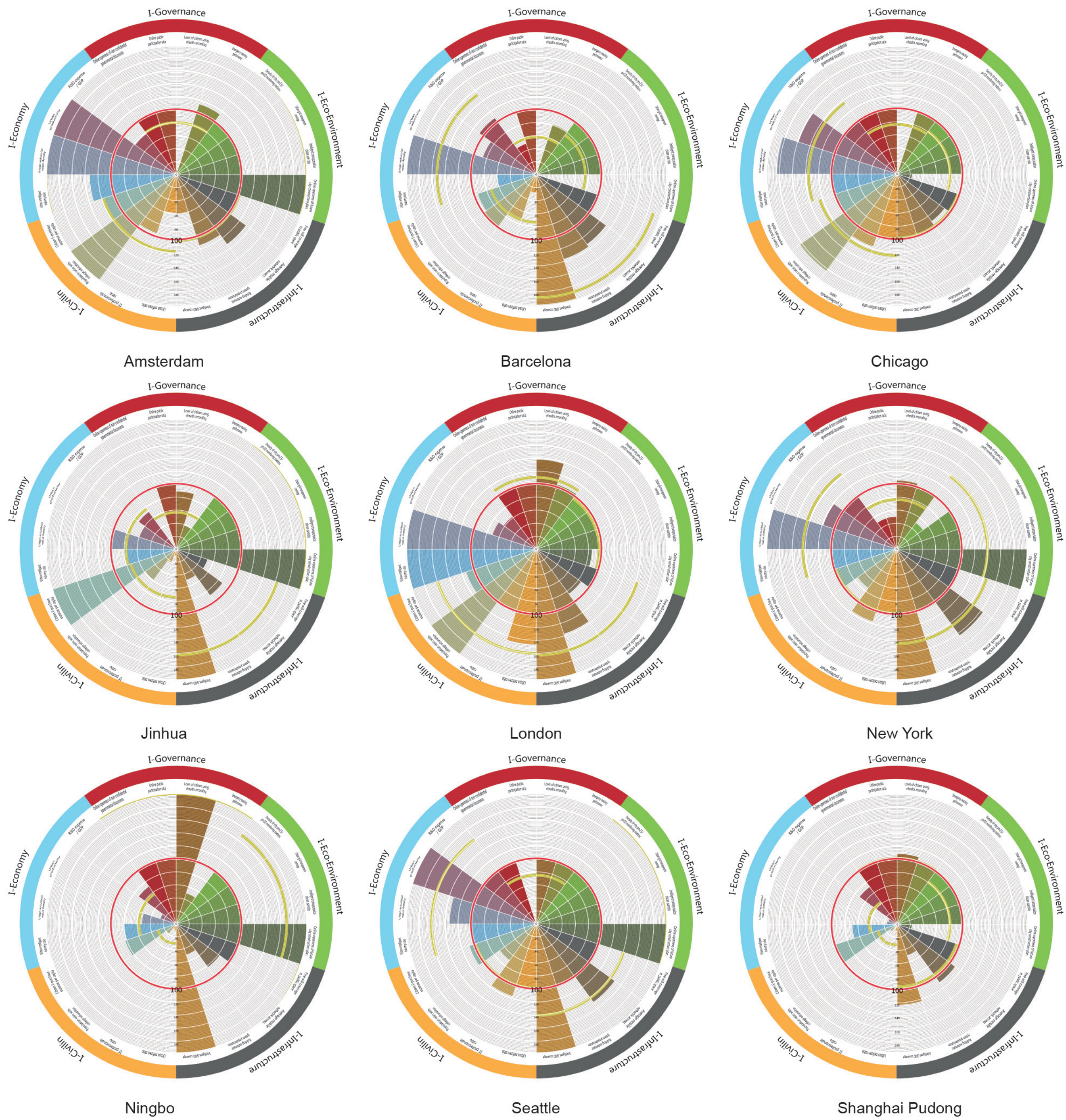

Fig. 8. Score compasses of the intelligence levels calculated by City IQ Evaluation System 3.0.

dynamically adjustable data sources. Thus, the system avoids the existing problems in current ICESs, including indirect data access, poor reliability, discrepant indicators, and the missing capability for dynamic adjustments. These features distinguish the City IQ Evaluation System from other ICESs.

(3) Learning from the ideology and approaches of the IQ test. In the intelligence evaluation of eight Chinese cities and 33 cities in Europe and the US, a relative value standardization approach was applied in the indicator scoring, dimension scoring, and comprehensive scoring. City IQ Evaluation System 2.0 sets the highest score received by the criteria city as the standard value. City IQ Evaluation System 3.0 further employs the deviation evaluation methods of IQ tests and makes modifications to the data standardization process, after which the average score of each indicator of the criteria city is set to 100 and other cities are evaluated according to this standard. The application of the IQ test concept and methods enhances the rational conception that intelligent cities are actually intelligent city-beings. Evaluation results prove the high sensitivity of the City IQ Evaluation System.

The City IQ Evaluation System series will be updated annually, and sustained improvements and upgrading will be provided on indicators and data sources. Finally, the City IQ Evaluation System will provide more valuable and credible evaluation results for advances in iCity construction, operation, and development.

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Fig. 9. Analysis of the City IQ Evaluation System 3.0 growth and development for 41 global iCities, based on evaluation results of the ICES intelligence level, 2015.

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Compliance with ethics guidelines

Zhiqiang Wu, Yunhe Pan, Qiming Ye, and Lingyu Kong declare that they have no conflict of interest or financial conflicts to disclose.

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