



IEEE Standard for Maturity Index of the Internet of Things— Evaluation, Grading, and Ranking

IEEE Industrial Electronics Society

Developed by the
Industrial Electronics Society Standards Committee

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STANDARDS

IEEE Standard for Maturity Index of the Internet of Things— Evaluation, Grading, and Ranking

Developed by the

Industrial Electronics Society Standards Committee
of the
IEEE Industrial Electronics Society

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IEEE SA Standards Board

Abstract: The maturity index of Internet-of-things (IoT), referred to as IDex, is defined in this standard. The formats for 1) the IDex and 2) the IDex database and the IDex evaluation model database are specified. The general mechanism of the IDex evaluation is defined as pertinent to the applications and technical fields of the IoT objects to be evaluated. The IDex can be applied to IoT devices, networks, applications, algorithms, hardware, software, systems, and infrastructure. With slight modifications, the IDex can be extended to evaluate objects and infrastructure in various services, such as smart city services.

Keywords: IDex, IEEE 2668™, Internet-of-things, maturity index

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Moe Alahmad	Ka Man Lee	Y.H. Shum
Allen Chen	Tony Lee	Hao Wang
Hao Ran Chi	Paulo Leitao	Yang Wei
Massimo Ficco	Jimmy Li	Woody Wu
Gerhard Hancke Jr.	Yucheng Liu	Joe Zhang
Gerhard Hancke Sr.	Hiroaki Nishi	Nan Zhou
Loi Lei Lai	Stefano Savazzi	Hongxu Zhu

The following members of the individual Standards Association balloting group voted on this standard. Balloters may have voted for approval, disapproval, or abstention.

Robert Aiello	Deborah Hagar	Weili Liu
Riccardo Brama	Werner Hoelzl	Aleksander Malinowski
Dietmar Bruckner	Victor Huang	Jiangbo Pu
Paul Cardinal	Piotr Karocki	Bartien Sayogo
Cheng-Jen Chen	Chun Sing Lai	Yuyin Song
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John D. Kulick	Jon Walter Rosdahl	Daidi Zhong

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Introduction

This introduction is not part of IEEE Std 2668-2022, IEEE Standard for Maturity Index of the Internet of Things—Evaluation, Grading, and Ranking.

This standard provides an overview of the Internet-of-things (IoT) Maturity Index (IDex) for evaluating, grading, ranking, and quantifying the performance of IoT objects. This standard also outlines the proposed IEEE P2668 family of standards and standard framework. In view of the complexity of the IoT environment, the IDex development is categorized into three phases, and multiple documentary categories are defined to enhance the completeness and applicability of the IDex. The details of the IDex development are presented in [Clause 4](#). In addition, related terms, the IDex format, IDex database structure, and a general evaluation flow of the IDex evaluation, are defined in this standard. The IoT architecture is standardized to make the IDex evaluation consistent and to facilitate the adoption of the IDex standard by IoT stakeholders.

This standard measures the maturity of objects in the IoT environment, namely IoT objects. IoT objects represent things or devices or the entire system. The IDex classifies the objects into multiple levels of performance and gives a quantitative representation and indication of the performance of objects. IDex manifests guidance on the blending of IoT objects to evolve into better performance.

The IDex standard aims to facilitate consumers, companies, and entities to compare, adopt, develop, and select IoT products efficiently, thus proliferating efficiency and making contributions to reduction in reconciliation costs, the efficiency of decision making, progress of international integration, and market integrity. The stakeholders of the IDex include manufacturers and users of IoT products, personal computers, enterprise networking devices, consumer electronic devices, home networking equipment, producers of industrial sensors, mobile devices, cellular operators, equipment manufacturers, vehicle manufacturers, private/public sectors, enterprise infrastructure providers, and wireless operators.

Attention is drawn to the fact that IDex facilitates an international integration, blending, and innovation to evolve into better performance through its open platform for IoT objects. Potential benefits of the IDex include the following:

- a) Provide a global standard of grading IoT objects that allows governments, businesses, manufacturers, personal users etc. to evaluate and compare the IoT objects in the market.
- b) Provide a quantitative multi-level IDex evaluation result that renders a direct ranking and comparison between IoT objects.
- c) Provide an adaptive IDex evaluation system that objectively evaluates the IoT objects pertinent to their services and infrastructural fields. It renders a universal evaluation system for all IoT objects.
- d) The IDex model keeps self-updating, thus rendering the adaptiveness of technology development and new IoT products.
- e) Provide a comprehensive evaluation of all IoT objects, from the device level to the system level.
- f) Provide a benchmark for all IoT products, facilitating consumers to evaluate and use the products in the IoT environment.

This standard is structured as follows:

- [Clause 1](#), Overview: Delivers the scope and purpose of this standard
- [Clause 2](#), Normative references: Lists the references to other standards and documents that are useful when adopting this standard

- [Clause 3](#), Definitions: Gives the definitions that are newly defined in this standard and/or have been modified for use with this standard
- [Clause 4](#), Need for the Internet-of-things Maturity Index (IDex): Justifies the rationales for adopting this standard and provides use-case examples of applying the IDex
- [Clause 5](#), Definition of IDex: Presents the definition of the IDex, including the format and general calculation of the IDex evaluation
- [Clause 6](#), The Framework of IDex Evaluation: Illustrates the evaluation structure and the database framework of IDex
- [Clause 7](#), The IDex Evaluation Mechanism: Describes the general IDex evaluation flow and gives an example of how the IDex evaluates IoT objects
- [Clause 8](#), IoT Architecture Reference: Presents the standardized IoT architecture including the device layer, network layer, application layer, and other essential standardized services

The following annexes are included for completeness:

- Informative [Annex A](#), An Example of the IDex Evaluation of Low-power Wide-area Network (LPWAN) Technologies: Provides an IDex evaluation example for LPWAN technologies
- Informative [Annex B](#), An IDex Example of Cybersecurity Consideration: Presents an IDex example of cybersecurity consideration
- Informative [Annex C](#), An Example of Data Accuracy Evaluation in terms of the IDex level: Provides a use case of adopting the IDex for indicating the accuracy of data
- Informative [Annex D](#), The IDex Example of Cybersecurity Consideration: Illustrates the IDex consideration example for evaluating the cybersecurity of IoT objects
- Informative [Annex E](#), IDex Use Case: Illustrates the scenario of adopting the IDex
- Informative [Annex F](#), Bibliography: Provides the bibliography for this document

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IEEE Standard for Maturity Index of the Internet of Things—Evaluation, Grading, and Ranking

1. Overview

1.1 Scope

The scope of this standard is to measure the maturity of objects in the Internet-of-things (IoT) environment, namely IoT objects. IoT objects shall represent things or devices or the entire system. This standard defines the mechanism and specifications for evaluation, grading, and ranking of the performance of IoT objects by using indicator values, referred as IoT index (IDex). IDex shall classify the objects into multiple levels of performance and give a quantitative representation and indication of the performance of objects. IDex shall manifest guidance on the blending of IoT objects to evolve as improved performance.

1.2 Purpose

This standard provides an objective, unique, transparent, and trustworthy measurement and indication of IoT objects pertinent to their performances. IDex consists of five levels and grades and classifies IoT objects, and it provides quantitative and trustworthy value to users and consumers who may then make decisions on the usage, adoption, and promotion of IoT objects. The establishment of IDex shall proliferate a rapid, positive, and mature progression of the IoT industry.

1.3 Word usage

The word *shall* indicates mandatory requirements strictly to be followed in order to conform to the standard and from which no deviation is permitted (*shall* equals *is required to*).^{6, 7}

The word *should* indicates that among several possibilities one is recommended as particularly suitable, without mentioning or excluding others; or that a certain course of action is preferred but not necessarily required (*should* equals *is recommended that*).

The word *may* is used to indicate a course of action permissible within the limits of the standard (*may* equals *is permitted to*).

The word *can* is used for statements of possibility and capability, whether material, physical, or causal (*can* equals *is able to*).

⁶The use of the word *must* is deprecated and cannot be used when stating mandatory requirements; *must* is used only to describe unavoidable situations.

⁷The use of the word *will* is deprecated and cannot be used when stating mandatory requirements; *will* is used only for statements of fact.

2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

There are no normative references in the standard.

3. Definitions, acronyms, and abbreviations

3.1 Definitions

For the purposes of this standard, the following terms and definitions apply. The *IEEE Standards Dictionary Online* should be consulted for terms not defined in this clause.⁸

criterion: A criterion is utilized for evaluating the maturity of an IoT object. The criterion is extracted from the specification and data of an IoT object for calculating the IDex level.

infrastructural field: A field or technology level of the IoT object to be evaluated. General infrastructural fields include device level, network level, application level, system level, infrastructure level, etc.

Internet-of-things (IoT) object: An object that implements in an IoT environment, including but not limited to a machine, controller, microprocessor, device, sensor, actuator, transducer, mobile, hardware tool, software tool, analyzer, network, topology, protocol, storage, algorithm, scheme, control, service, system, application, infrastructure, etc., and combinations thereof.

3.2 Acronyms and abbreviations

CIA	confidentiality, integrity, and availability
CoAP	Constrained Application Protocol
DIS	Digital Information Specification
DPM	Data Processing Middleware
IDex	Internet-of-things maturity index
HTTP	Hypertext Transfer Protocol
IoT	Internet-of-things
LPWAN	Low-power Wide-area Network
MQTT	Message Queuing Telemetry
PID	Platform Interoperable Device
PSI	policy, service, and infrastructure
TCP	Transmission Control Protocol
UDP	User Datagram Protocol

4. Need for the Internet-of-things maturity index (IDex)

The popularization of the IoT has tremendously proliferated various fields of research and technology, to name a few, smart city applications, smart transportation, smart agriculture, smart living, smart grid, etc. Owing to the significant IoT achievement, the number of connected IoT objects would exceed 50 billion

⁸The *IEEE Standards Dictionary Online* is available at: <http://dictionary.ieee.org>. An IEEE Account is required for access to the dictionary, and one can be created at no charge on the dictionary sign-in page.

by 2050 [B1]. The IoT objects refer to various connected things, including devices, networks, algorithms, management processes, systems, applications, services, infrastructures, etc. The IoT objects may have different specifications, applications and requirements, making the evaluation of IoT objects difficult. Unregulated IoT development and lack of IoT standardization may result in interoperability issues and underlying cyber threats, thereby deteriorating the performance and safety of IoT infrastructures. The IoT development is currently encountering the following challenges:

- The design and implementation of IoT infrastructure
- IoT security assessment and measures
- The interoperability between different IoT solutions and/or infrastructure
- The wise selection of IoT technologies
- The adoption and integration of new IoT technologies
- The objective and standardized evaluation method for IoT objects

The IDex is defined to overcome the captioned challenges. This standard defines the mechanism and criteria for the evaluation of IoT objects pertinent to their applications and performance. The evaluation result is quantified as an indicator value, namely the IDex. The IDex classifies the maturity of the IoT objects into five levels, ranging from one (the lowest maturity) to five (the highest maturity), meeting the IoT stakeholders' demand for obvious indication and comparison of IoT objects. In addition, the IDex is applicable for predicting the performance changes under different operating environments and manifesting the guidelines for improving the performance of IoT objects.

The IDex platform can evaluate the maturity of the IoT objects based on the defined IDex evaluation models and provide a quantified indication of the evaluation result. The platform can further provide advice to further improve the IDex level of the IoT objects and estimate the IDex level if the improvement advice is implemented.

In addition, the IDex platform enables third-party utilities to contribute to the development of the IDex database. The platform encourages IoT integration to enhance product maturity and create innovative IoT solutions. The provisional IDex is defined to estimate and forecast the IDex level of a conceptual integration of IoT solutions before implementing practical integration, thus shortening the IoT development cycle and proliferating transnational cooperation.

Furthermore, by inputting different operating environments for the IoT solutions, the IDex platform can estimate and forecast the changes on the IDex level, facilitating the IoT stakeholders to manage and sustain the IoT solutions for various operating environments.

In brief, the IDex makes the following contributions:

a) Smart development of IoT solutions

The IDex can quantify the maturity of the IoT objects pertinent to their applications and specifications and thus issues an IoT label. The IoT stakeholders can compare, adopt and develop IoT solutions in compliance with the IEEE standard, therefore proliferating IoT production efficiency, product safety, cybersecurity, and data privacy. For instance, the policymakers can perform risk analysis and assessment on IoT product safety and set the minimum safety requirement using the IDex, e.g., the IDex threshold value.

b) High interoperability

The IDex can provide a common and open platform to other utilities for contributing to the IDex database. The platform aims to foster the integration among various IoT solutions for enhancing the IDex levels of the IoT products. Meanwhile, the platform will be aware of the interoperability

when integrating multiple IoT solutions. Ultimately, the IDex platform will yield an interoperable integration plan that reaches a compromise between development cost and solution performance. This compromise will be essential to cybersecurity in IoT. Different from conventional smart devices, IoT devices are usually adopting lightweight and low-cost designs, and some IoT devices even lack security measures for decreasing the development cost. The lack of cybersecurity measures may expose IoT infrastructure and sensitive information to the risk of cyberattacks. The IDex is being developed to cater for all these concerns.

c) High service resilience and dependability

The IDex can anticipate the performance changes of the IoT solutions due to the ever-changing operating environment and can further provide feedback for improving the resilience and dependability of IoT solutions (i.e., the ability to deliver IoT services that can justifiably be trusted). Resilience and dependability have a quite general scope and also comprise reliability, maintainability, and security. Also, the IDex will analyze various events that could lead to system failures and provide advice to help avoid/recover system failures. For example, if an IoT network suffers traffic congestion frequently, the IDex will identify the source of the problem and provide the network operator with various solutions, such as increasing the network bandwidth and dividing the network into multiple sub-networks, to mitigate the risks.

4.1 Examples of the IDex application

4.1.1 Cybersecurity measures

An example of the IDex application on cybersecurity measures is introduced to help explain the aforementioned concepts. Given an IoT development project is seeking a cybersecurity evaluation, which could be on the device level, network level, and/or application level. The project manager can input the application requirements and project specifications into the IDex platform. The IDex platform will perform the following tasks:

a) IDex evaluation on project cybersecurity and advice for project improvement

The IDex platform performs maturity evaluation based on the received information, i.e., application requirements and project specifications. Afterward, the platform provides a quantified indication of project security level in terms of the IDex level, ranging from one (the lowest) to five (the highest). The platform then delivers a list of recommendations to improve the security level of the project, such as revising encryption methods, adopting blockchain technology for the transaction, etc. The IDex platform will estimate the respective IDex changes for every recommendation.

b) Provisional IDex level for integration

The IDex platform consolidates the information shared by various utilities. If the project would like to adopt other IoT solutions provided by other utilities, the platform will estimate a provisional IDex level to estimate and forecast the IDex level of the conceptual integration between the existing project and other IoT solutions.

c) Performance prediction of the various operating environments

The platform enables multiple inputs of operating environments and produces respective IDex levels for the project under different operating environments. Also, the platform will provide feedback to indicate potential risks and solutions, such as enhancing confidentiality, increasing network bandwidth for sustaining availability, etc.

4.1.2 Smart Tendering

The supremacy of the IDex is providing an objective, trustworthy, and comparable performance evaluation, thus yielding a highly efficient selection of IoT solutions. There are tons of IoT solutions offered by a wide variety of utilities that may pose various challenges to the wise selection of IoT solutions. Smart Tender, as one of the IDex

use cases, can be conceived as one of the best candidates to overcome the captioned challenge. When originating a tender, the client can define the project applications and specify the requirements on the IDex platform. Afterward, the IDex platform will evaluate and rank all the utilities' bids based on the client's specifications. The client can define the screening criterion in terms of the IDex level. The quantified label of the IDex and the IDex evaluation results will deliver a perspicuous suggestion to the client and shorten the procurement period. On the other hand, the IDex platform will provide feedback to the utilities and help them improve the IoT projects.

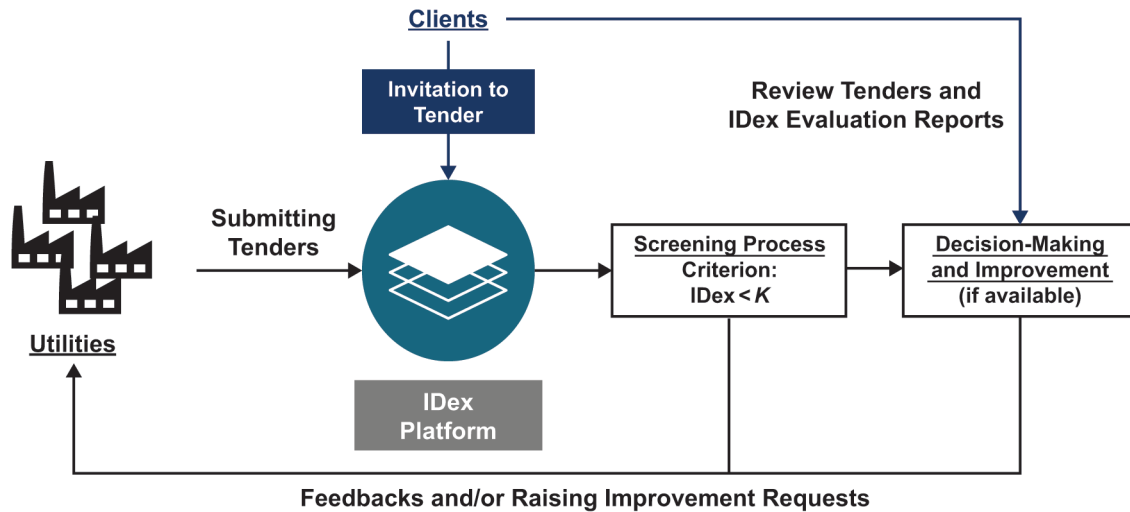


Figure 1—Example of the IDex application on Smart Tender

4.1.3 Regulation of transport safety

Different Smart City applications and services may demand various specifications and requirements of the IoT solutions. The IDex helps promulgate the guidance pertinent to their demands. Taking safety guidance of road traffic safety as an example, the IDex can quantify and classify the safety features of the vehicles into five IDex levels. For instance, a higher IDex level can be issued to the vehicles equipped with anti-collision systems, and a lower IDex level can be issued to the vehicles equipped with low-accuracy object detection technology. The policymakers can review the criticality of each road and define the minimum safety requirements. For example, vehicles with a low IDex level (IDex 3 to 3.5) are permitted for use on low-traffic roads, but they shall be declined on high-traffic roads and public transport. Only the vehicles whose IDex is outstanding (≥ 4.5) can be adopted in critical transport infrastructures, thus protecting public safety. The IDex of smart vehicles and the requirements of IDex level on transportation safety can be updated in response to the progress of vehicle technologies.

4.2 The framework of the IDex family of standards

The IEEE 2668 framework is intended to measure the maturity of objects in the IoT environment, namely IoT objects. The development of the IEEE P2668 family of standards includes the following three phases:

- Phase 1: Short-term development

Short-term development refers to the compulsory standards development, and the standard development is expected to commence within one to three years after the publication of this standard.

- Phase 2: Mid-term development

Mid-term development refers to the essential standards development to audit the operation of the IEEE P2668 family of standards. It is expected to commence within one to five years after the publication of this standard.

— Phase 3: Long-term development

Long-term development refers to the substantial standards development to sustain and improve the IEEE P2668 family of standards throughout the standards lifecycle. It is expected to commence within one to eight years after the publication of this standard.

The IEEE P2668 framework and family of standards family is listed in [Table 1](#).

Table 1—The framework for the IDex family of standards

Document categories	Published and proposed standards ^a	Phase of development
(I) Overview, Definition, and Framework	IEEE Std 2668-2022: Overview, Standard Framework, and Terms Definition	1
(II) Evaluation	P2668.1: Internet-of-things Index (IDex) Evaluation – Requirements, Categories, Criteria, and Mechanisms (Application-neutral and Technology-neutral)	1
	P2668.2: Circumstances and Regulations for Bodies Providing Audit and Certification of IDex	2
(III) Guideline	P2668.3: The Best Practices for IoT Solution Development in Compliance with IDex	2
	P2668.4: IDex Evaluation and Practices for Improvement – Implementation Guidelines	3
	P2668.5: IDex – Analysis and Measurement	2
	P2668.6: IDex – Guidelines for IDex Evaluation Auditing	2
	* P2668.7 – P2668.9 (Reserved for Future Use)	2
	P2668.10.1: IDex Evaluation on Smart City Maturity	2
(IV) Service-specific	P2668.10.2: IDex Evaluation on Energy Management	After Phase 1
	P2668.10.3: Safety	
	P2668.10.4: Building and Construction	
	P2668.10.5: Smart Infrastructure	
	P2668.10.6: RF Modelling	
	P2668.10.7: Photonics	
	P2668.10.8: Healthcare	
	P2668.10.9: Robotics	
	P2668.10.10: UAV, drones	
	P2668.10.11: Vehicles	
	P2668.10.12: Smart mobility (logistics, pedestrians)	
	P2668.10.13: Agriculture	
	P2668.10.14: Aviation	
	P2668.10.15: Shuttle, Space	
	P2668.10.16: Satellite	
	P2668.10.17: Quantum computation	
	P2668.10.18: Internet of Things Cyber Security	
	...	

^aAt the time of publication, numbers preceded by P indicate projects proposed by the Working Group that have not yet been approved by IEEE.