# Internet of Bicycles
## *Tracking and Monitoring Life-cycle Information using GS1*

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Abstract: Social phenomena such as the rise of cyclists, the expansion of public bicycle systems and the increase of bicycle thefts highlight the needs of tracking a bicycle's life-cycle and implementing new services based on information from a bicycle's life-cycle. We suggest Global Bicycle Information Architecture to describe and save a bicycle's life-cycle. We extend the GS1 EPCglobal architecture for Global Bicycle Information Architecture to identify bicycles and capture and share information. Global Bicycle Information Architecture enables stakeholders to gather information that can be used to formulate public policies or for protection of property – in this study, bicycles. We verify the availability of Global Bicycle Information Architecture with the implementation of a bicycle tracking system.

# 1 INTRODUCTION

Even though there is no generally accepted definition of the Internet of Things (IoT), IoT generally refers to a network of physical or virtual things that enables these objects to collect and exchange data. The network connectivity of "things" means that IoT finds applications almost every industry including healthcare, utilities and transport (Sundmaeker et al., 2010). According to Gartner, Inc., there will be nearly 26 billion devices on IoT by 2020 (Gartner, 2013).

Intelligent bicycles become a part of smart cities since they exchange information with traffic systems (e.g. traffic lights, public transportation system) and connected cars to improve the citizen life, help avoiding/reducing accidents and so on (Dezani, 2015).

In addition, many countries have public bicycle systems, known as bicycle-sharing systems. From 2000 to 2014, the number of cities with a bicycle-sharing system increased by approximately 214 times (Russell, 2015). However, these systems cannot be connected with each other because they use different identification systems for the users and bicycles (Erlanger, 2009).

However, bicycle thefts also have increased. According to statistics from the United Kingdom, 536,166 cases were reported from 2008 to 2013 (Moss, 2014). But only 1 in 4 bike thefts are reported to the police. This means that almost 2.1 million bicycles are stolen over five years. These social phenomena show the need for tracking a bicycle's life-cycle and implementing new services based on information from the life-cycle.

In 2014, the Netherlands Organisation for Applied Scientific Research released a prototype of the country's first intelligent electric bicycle, which could be available to consumers within the next two years according to The Telegraph (Telegraph Men, 2014). Similar to recently released connected cars, the bicycle is designed to warn its rider of oncoming dangers with electronic devices. This approach is aimed at reducing accidents, but does not try to connect other bicycles or share information.

Recently connected bicycles also have been studied. Connected bicycles exchange information with other connected bicycles to help cyclists avoiding traffic jams or maintaining a safe distance. But this approach only focuses on the connection between bicycles (Cespedes et al., 2014).

The present research suggests Global Bicycle Information Architecture which is an Internet of



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Things framework for bicycles as a solution of these social phenomena. This framework provides a model of activities in a bicycle's life-cycle and enables stakeholders to capture and share information about the life-cycle of bicycles based on Global Standard 1 (GS1).

For decades, GS1 has provided multiple standards that enable industries to identify items and capture and share information from their identifiers.

GS1 suggests three steps based on the life-cycle of information – Identify, Capture and Share. These three steps enable information to be uniquely identified and captured with a general format and shared automatically. This concept is also applied to the Internet of Bicycles to identify bicycles, capture event data during the life-cycle of bicycles and share data with other users.

Global Bicycle Information Architecture also enables bicycles to connect with other bicycles, mobile phones, cars and a traffic control system to give people information and protect people's property – bicycles in this research. This information can be used for a country's bicycle-registration policy, a recall service and other security services to track bicycles with a globally unique identifier.

This paper is organised as follows: Section 2 introduces the GS1 architecture, which gives the basic structure of Global Bicycle Information Architecture. Section 3 provides Global Bicycle Information Architecture suggested in this study. In section 4, we show the practical use of Global Bicycle Information Architecture by implementing a bicycle tracking service and finally conclude our paper in section 5.

# 2 GLOBAL BICYCLE INFORMATION ARCHITECTURE

This research provides an Internet of Bicycles named Global Bicycle Information Architecture. Global Bicycle Information Architecture is an architecture that enables stakeholders to identify bicycles and capture their information and share information to other stakeholders.

Information from bicycles is usable for manufacturers to manage their products, retailers to manage their goods, end users to track their properties and governments to manage a public bicycle sharing system and order recall. Also this information can be an opportunity to service providers.

In this architecture, we generalize a bicycle's life-cycle in four steps – manufacture, sell, public/private use and disuse. Each step has one or more stakeholders who generate a business step and make information or events. This architecture consists of stakeholders and their systems to capture information and Electronic Product Code Information Service (EPCIS) elements to share information.

In section 2.1 and 2.2, this paper introduces Electronic Product Code (EPC) Network Architecture and Oliot which are based on Global Bicycle Information Architecture. Section 2.3 provides Global Bicycle Information Architecture including the information needs based on a bicycle's life-cycle. This paper describes a bicycle's life-cycle in four steps and suggests an abstract model of each step in section 2.4. This model enables stakeholders in the architecture to share and understand information equally.

## 2.1 EPC Network Architecture

The EPC Network Architecture provides the basic structure for the Internet of Bicycles. There are two major elements that are different from a standalone database system:

- EPCIS
- Object Naming Service (ONS)

To gather information, people need to identify a target object. For this reason, GS1 provides eleven categories to give globally unique keys such as trading, location or shipping.

For the Internet of Bicycles, this research uses Global Trade Item Number (GTIN) because the life-cycle of bicycles starts from the manufacture of the bicycle and GTIN gives an advantage to describe products as US food supply has shown (Krissoff et al., 2004).

After identifying a target thing, EPCIS can capture information by its capturing applications and share information by its access applications. To query information to other EPCIS all over the world, EPC Network Architecture provides ONS to find where queried information is.

The Internet of Bicycles described in this paper also uses the EPC Network Architecture to share information from bicycles such as their status (e.g. in stock, parked, being ridden or stolen), whether they are registered as public bicycles or if they have been stolen.

## 2.2 Oliot: Open Language IoT

Oliot is an open source project to build an ID-centric IoT Platform developed at Auto-ID Lab in KAIST. Oliot implements the platform based on GS1 identification standards such as URI-convertible GTIN.

Oliot enables identification of intelligent things and capturing and sharing of information with each other. Oliot supports passive and active tags, various sensors and actuator networks (e.g. Barcode, Zigbee, 6LoWPAN). Oliot has an approach that integrates IoT-related projects. For instance, Oliot EPCIS shows possibility of application to healthcare (Byun and Kim, 2015).

The Internet of Bicycles described in this paper is derived from Oliot's concept.

## 2.3 Global Bicycle Information Architecture

To identify, capture and share information about bicycles, Global Bicycle Information Architecture consists of three major actions, as the GS1 architecture describes:

- 'Identify' bicycles
- 'Capture' information from bicycles
- 'Share' information to others

This architecture uses an identification policy based on SGTIN. GTIN is an identifier for trade items and it enables manufacturers to describe a product easily. GTIN includes a company and a product reference number. GTIN is also helpful to order a recall to manufacturers and retailers because a product reference number in GTIN generally includes a model number. To identify a specific bicycle, this architecture uses SGTIN to identify it and provides a manufacturer's original serial number as an extension.

Information that Global Bicycle Information Architecture captures should be useful for general purposes. For example, manufacture and sell information is necessary when a government orders a recall to manufacturers and retailers. Riding or parking (use) information is useful when a government appropriates budget to build bicycle roads or parking facilities.

To capture and share information about bicycles, this architecture includes EPCIS and ONS. EPCIS and ONS enable Global Bicycle Information Architecture to generate and save information based on the global standards.

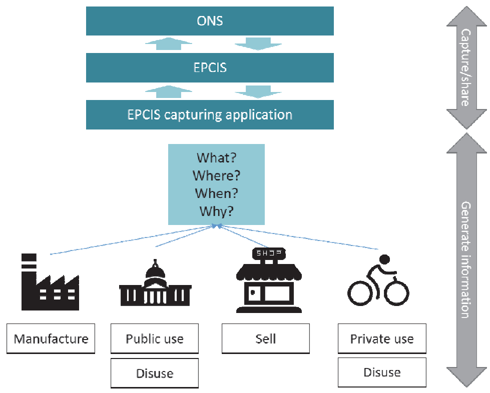


Figure 1: Global Bicycle Information Architecture.

Figure 1 shows an overview of Global Bicycle Information Architecture. The stakeholders generate information from four business steps – manufacture, sell, public and private use and disuse. The generated information is captured by EPCIS capturing applications installed in the stakeholders' environment. The captured information is stored in EPCIS. ONS guides applications in terms of where they need to save information and where they can find other information.

## 2.4 Bicycle Object and Process Modelling

Bicycles are used as 'objects'. This means that a bicycle and its related events should be generalized and abstracted. In this section, we describe necessary steps and define what should be saved. For example, if a bicycle is registered as a public bicycle, the public enrolment step should be modelled. To describe this step, the following information is registered: which bicycle it is, when it is registered, how long it serves as a public bicycle and where it is located.

For event data and master data, GS1 Core Business Vocabulary Standard (CBV) is applied in this architecture. This architecture also defines new user vocabularies to describe a bicycle's events.

### 2.4.1 Bicycle Process Modelling

For Global Bicycle Information Architecture, we define four stakeholders: manufacturers, retailers, governments, and end users. The following eleven actions are considered as steps of a bicycle's life-cycle:

- A manufacturer makes a bicycle.
- A manufacturer sells a bicycle to a retailer.

- A retailer sells a bicycle to an end user or a government.
- A government registers a bicycle as a public bicycle system.
- An end user registers a bicycle into a government.
- An end user rents a public bicycle.
- An end user returns a public bicycle.
- An end user rides a (public/private) bicycle.
- An end user stops riding a (public/private) bicycle.
- A (public/private) bicycle is stolen.
- A bicycle theft is reported to a government (police office).
- A bicycle ends its life-cycle.

Figures 2 shows a bicycle's general life-cycle from production to disuse.

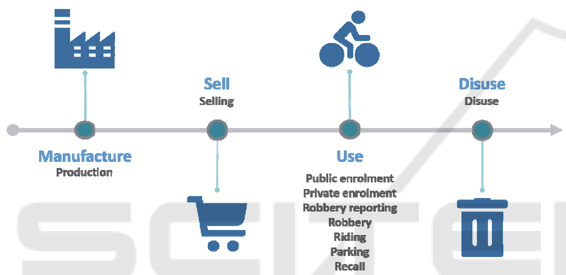


Figure 2: A Bicycle's Life-cycle and Events Overview.

These actions become event data that are saved in EPCIS:

Table 1: Event and its description.

| Event | Description |
|---|---|
| Production | A manufacturer makes a bicycle. |
| Selling | A retailer sells a bicycle to a government or an end user. |
| Public enrolment | A government enrols a bicycle for public purposes. |
| Private enrolment | An end user enrols a bicycle to a government. |
| Disuse | A bicycle ends its life-cycle. |
| Robbery reporting | A bicycle theft is reported to a government (police office). |
| Robbery | A bicycle is stolen. |
| Riding | An end user rides a bicycle. A public bicycle is rented when an end user rides. |
| Parking | An end user stops riding a bicycle. A public bicycle is returned when an end user stops riding. |
| Recall | A government orders a recall campaign to a manufacturer or a retailer. |

Each event is described in the next section. These actions can be extended, especially 3rd party services such as insurance, a security service, and so on. Furthermore, each event is translated as a business step keyword described in Table 2.

Table 2: Event and its business step.

| Event | Business Step | Subject |
|---|---|---|
| Production | manufacturing | Manufacturer |
| Selling | retail_selling* | Retailer |
| Public enrolment | public_enrol (add/delete) | Government |
| Private enrolment | private_enrol (add/delete) | End user |
| Disuse | destroying* | Government/ end user |
| Robbery reporting | robbery_reporting (add/delete) | Government |
| Robbery | robbery | End user |
| Riding | riding | End user |
| Parking | parking | End user |
| Recall | order_recall | Government |

(*: defined core business step in CBV)

### 2.4.2 Bicycle Data/Object Modelling

All information generated by bicycles must be changed to the format of EPCIS event data to save it in the EPCIS server. Based on the GS1 architecture, event data should have the following '4W' structure:

- What
- When
- Where
- Why

In this section, we define eight business steps of a bicycle (two other business steps are already defined in CBV), two dispositions and extensions to give more information. We also suggest a new namespace 'bicycle' to mark these events. These vocabularies and namespace should be included in the standard.

### 2.4.3 4W: What

The "WHAT" dimension indicates the objects to which the EPCIS event pertains.

Each observed bicycle should be captured in a separate ObjectEvent. The epcList element should contain only the SGTIN of the observed bicycle. To specify a bicycle for its manufacturer, this architecture also suggests the extension 'serialNumber' described in section 2.4.2.4.

### 2.4.4 4W: When

The "WHEN" dimension serves as a timestamp for the EPCIS event.

The eventTime of Object events should reflect the time at which the bicycle was observed. In addition, the recordTime reflects the date and time at which this event was recorded by an EPCIS Repository.

### 2.4.5 4W: Where

The “WHERE” dimension component indicates the location at which the EPCIS event was observed, as well as the whereabouts of the object subsequent to the event.

The readPoint – indicates the SGLN corresponding to the event’s location. In this process, it could be a factory, a shop, a government or a parking facility.

The bizLocation – indicates the SGLN corresponding to another related location. For example, a ‘Robbery reporting’ event has a readPoint of government (police office) and a bizLocation of the place where the bicycle went missing.

This architecture also allows an extension that enables GPS location directly. For all object events and transaction events either the readPoint or the bizLocation or both should be specified.

### 2.4.6 4W: Why

The “WHY” dimension reflects the business context (“Business Step”) of the EPCIS event, as well as the status (“Disposition”) of the object subsequent to the event. The Core Business Vocabulary (CBV) defines standard values for these.

A Business Step specifies the business process linked to the EPCIS event. Two of Business Step identifiers are specified in section 7.1 of the CBV (GS1, 2014). Other business steps are newly defined in Table 2.

The Disposition denotes the status of a bicycle, subsequent to the EPCIS event. The Disposition is assumed to hold true until a subsequent event indicates a change of disposition. Disposition identifiers are specified in section 7.2 of the CBV. The following disposition identifiers are applied in this architecture:

Table 3: Disposition and its description.

| disposition value | Description |
|---|---|
| enabled | The bicycle’s service or registration activated |
| disabled | The bicycle’s service or registration deactivated |

All of these elements should be specified using the suggested namespace ‘bicycle’ for various extension elements. These extension elements give extra information of each event. For example, when a user registers his bicycle to a government, a user’s identification is necessary.

Table 4: Extension and its description.

| extension value | Description |
|---|---|
| serviceLife | It indicates the durability of the public bicycle. |
| serialNumber | It indicates the serial number of the bicycle generated by a manufacturer. |
| userIdentifier | It indicates a personal identifier for the specification of the owner. It should follow their country’s law. |
| recall_parts | It indicates a part or a set of parts related to a recall order. CPID is used for it. |
| distance | It indicates the distance between a bicycle and a rider. |

### 2.4.7 Biportal XSD Example

Figure 3 shows an example of XML Schema Definition for events in Global Bicycle Information Architecture. It describes two additional dispositions and five extensions and these data types (e.g. string, integer).

```
  <!-- extend disposition vocabularies -->
  <xs:simpleType name="disposition">
    <xs:restriction base="xs:string">
      <xs:enumeration value="enabled"/>
      <xs:enumeration value="disabled"/>
    </xs:restriction>
  </xs:simpleType>

  <!-- extend extension vocabularies -->
  <!-- describe a bicycle's serial number -->
  <xs:simpleType name="serialNumber">
    <xs:restriction base="xs:string"/>
  </xs:simpleType>
  <!-- describe a public bicycle's service life -->
  <xs:simpleType name="serviceLife">
    <xs:restriction base="xs:integer"/>
  </xs:simpleType>
  <!-- describe an owner's identifier based on the country's law -->
  <xs:simpleType name="userIdentifier">
    <xs:restriction base="xs:string"/>
  </xs:simpleType>
  <!-- describe which parts in a bicycle are for recall -->
  <!-- CPID is used -->
  <xs:simpleType name="recall_parts">
    <xs:restriction base="xs:string"/>
  </xs:simpleType>
  <!-- describe distance between a bicycle and a rider/observer -->
  <xs:simpleType name="distance">
    <xs:restriction base="xs:integer"/>
  </xs:simpleType>
</xs:schema>
```

Figure 3: XML Schema Definition Example.

## 3 IMPLEMENTATION

We provide BiPortal service to implement Global Bicycle Information Architecture and its utilization. Figure 4 shows a virtual image of the BiPortal service.

Figure 4: BiPortal Installation Example.

BiPortal service is a security service that enables smartphones to detect a thief and track stolen bicycles with a beacon installed on a bicycle and a surveillance device installed on a fixed place such as a parking facility. Information generated by BiPortal is saved and shared through Oliot EPCIS.

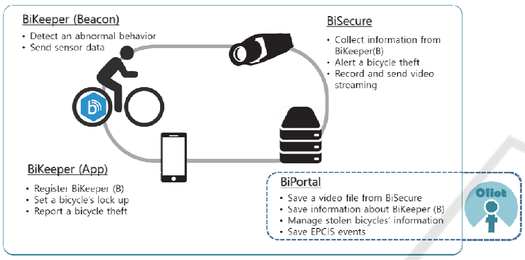


Figure 5: Elements in BiPortal system.

To build BiPortal, we implement four elements – BiKeeper (Beacon), BiKeeper (Application), BiSecure and BiPortal – as described in Figure 5 and Table 5.

Table 5: Elements and their characteristics.

| Elements | Characteristics |
|---|---|
| BiKeeper (Beacon) | - Detect an abnormal behaviour<br>- Send sensor data<br>* BiKeeper(B) |
| BiKeeper (Application) | - Register BiKeeper (Beacon)<br>- Set a bicycle's lock up<br>- Report a bicycle theft<br>* BiKeeper(A) |
| BiSecure | - Collect information from BiKeeper (Beacon)<br>- Alert a bicycle theft<br>- Record ad send video streaming |
| BiPortal | - Save a video file from BiSecure<br>- Save information about BiKeeper (Beacon)<br>- Manage stolen bicycles' information<br>- Save EPCIS events |

BiPortal has three layers as shown in Figure 6:

- Service (include BiKeeper(A))
- Server (include BiPortal)
- Hardware (include BiKeeper(B), BiSecure)

The service layer provides a user interface and a server interface. This layer is implemented as a mobile application. A mobile application captures information from sensors and sends information to the server layer. The server layer, including ONS, EPCIS and an application server, is for saving and sharing information.

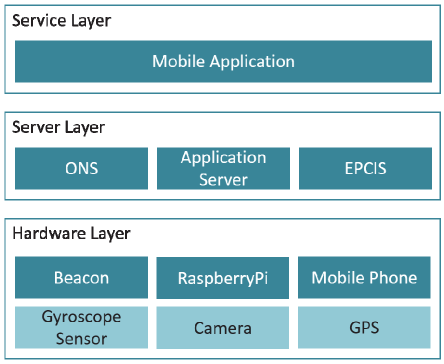


Figure 6: Service Components.

The hardware layer generates information from sensors in a beacon and a mobile phone. In this service, we use a gyroscope sensor in a beacon and a GPS in a mobile phone. A camera on a RaspberryPi is used as CCTV for bicycles.

## 3.1 Oliot IoT Platform

We apply Oliot EPCIS to save and share information from bicycles. Oliot EPCIS provides web service interfaces. We install Oliot EPCIS on the OpenStack-based cloud service to use it.

To provide the BiPortal service, we choose four bizStep values – private_enrol, robbery_reporting, riding and parking – from Global Bicycle Information Architecture.

Table 6: Business step and its description in BiPortal.

| bizStep value | Description in BiPortal |
|---|---|
| private_enrol | A beacon is registered to BiPortal service. |
| robbery_reporting | A stolen bike is reported to BiPortal service. |
| riding | An end user rides a bicycle. |
| parking | An end user stops riding. |

## 3.2 BiPortal Service

BiPortal service has two major features, a thief alarm and stolen bicycle tracking.

To use BiPortal service, a user attaches BiKeeper(B) to his bicycle. BiKeeper(B) has a gyroscope sensor to detect abnormal behaviour from thieves. BiKeeper(B) sends the Received Signal Strength Indication (RSSI) and gyroscope sensor data to BiKeeper(A) or BiSecure.

After attaching BiKeeper(B), a user who joins the BiPortal service provides his bicycle and beacon identification to BiKeeper(A). This information is used for a user and his bicycle's specifications.

This application saves login data and a user's bicycle information to an application server, and this information can be saved in EPCIS. The application obtains event data about riding, parking and robbery reporting.

BiSecure is installed on a parking facility for bicycles. When BiSecure obtains information from nearby bicycles, it will send information to an application server too. For BiSecure, a video camera that enables users to watch their bicycles directly is also installed.

### 3.2.1 Function 1: Thief Alarm

To detect a theft events, this application has two features:

- Detect with distance
- Detect with vibration

In a parking state, if an abnormal vibration is detected, this application notifies the owner with a display and sound. Or if the bicycle is moved far from the user in the parking state, this application also notifies the owner with a display and sound. If a bicycle is stolen, the owner can record the bicycle as stolen state.

The average cycling speed is 19.3km/h according to Road-bike.co.uk (Road-bike.co.uk, n.d.). This means a thief can move about 320 meters within a minute on a stolen bicycle. Hence, this application alerts users at distance of less than 50 meters so that it will be possible to reach a thief before he or she escapes.

### 3.2.2 Distance based on a Beacon

RSSI is the general metric used to define the distance between a beacon and its observing device – BiSecure or BiKeeper(A) in this case. It is based on the TXPower level. Because of its characteristics, the distance is not accurate when there are any obstacles nearby.

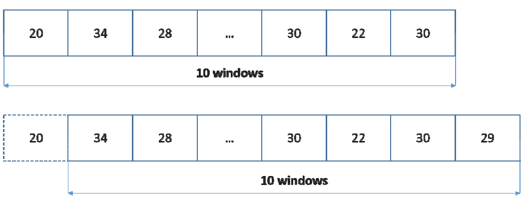


Figure 7: RSSI Windows.

To increase the accuracy, this application suggests 'windows' logic. The application uses ten windows to obtain RSSI data and calculate an arithmetic mean. Figure 7 shows the suggested windows logic.

There is no abnormal data removal because it is not possible to calculate the mean if an abnormal RSSI value is removed from a beacon. Given TXPower and RSSI values are transformed to distance based on the following code from Android Beacon Library (Android Beacon Library, n.d.):

```
double ratio = rssi*1.0/txPower;
if (ratio < 1.0) {
    return Math.pow(ratio,10);
}
else {
    double accuracy =
(0.89976)*Math.pow(ratio,7.7095) + 0.111;
    return accuracy;
}
```

### 3.2.3 Function 2: Stolen Bicycle Tracking

People who use this service are able to track a stolen bicycle's location. If a stolen bicycle is observed, this application gives location information to the stolen bicycle's owner.

Because of a privacy issue, this application only tracks GPS location and a bicycle identifier. The bicycle identifier and the owner information are invisible to other users.

## 3.3 Demonstration

A user who uses BiPortal service can receive an alarm and a screenshot as in Figure 8. The picture on the left shows a 'steal catch' alarm when abnormal behaviour is detected from the bicycle. The picture on the right shows live video from a camera attached on BiSecure.

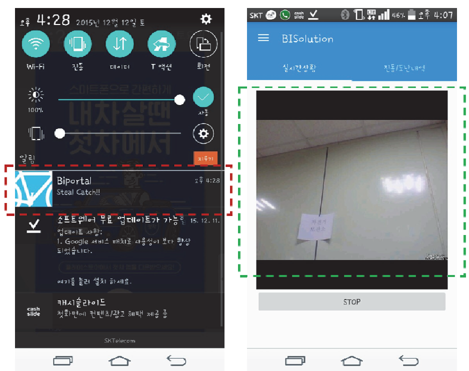


Figure 8: BiPortal Application Example.

# 4 CONCLUSIONS

Global Bicycle Information Architecture based on GS1 provides connections between stakeholders. These connections become the basis of information sharing. This idea also enables services that can protect people's property and help governments manage public bicycle systems or appropriately allocate budget to build bicycle roads and bicycle parking facilities.

Global Bicycle Information Architecture also enables industries to find opportunities for providing various services such as the bicycle portal service described in this research.

This research suggests a merged identification system that uses SGTIN and manufacturer's serial number together to identify each object and retain the manufacturer's original traceability. In addition, it enables governments to trace recalled bicycles easily using GTIN.

Based on this research, stakeholders related to bicycle industries should expand Global Bicycle Information Architecture and find vocabularies which are not defined in this research.

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