Technical Report

ISO/TR 25221

Electronic fee collection — Image-based tolling systems — Measurable characteristics

Perception de télépéage — Systèmes de péage basés sur l'analyse d'images — Caractéristiques mesurables

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Contents

Page

Foreword

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This document was prepared by Technical Committee 204, *Intelligent transport systems*.

Any feedback or questions on this document should be directed to the user’s national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

The European Commission Implementing Regulation (EU) 2020/204[15] on detailed obligations of European electronic toll service providers includes among the allowed tolling techniques: "electro-optical imaging systems at the toll charger's fixed or mobile equipment at the roadside, providing means for automatic number plate recognition (ANPR), in EFC systems where the installation and use of an OBE is not required."

ISO/TR 6026, produced by ISO/TC 204 in collaboration with CEN/TC278, identifies necessary areas of standardization for image-based tolling. Activities to revise existing EFC standards to support ANPR technologies have already been started.

It is well known that certified equipment is required, when ANPR is used for purposes other than tolling (for example, limited traffic zones and speed limit enforcement), and that certification activity requires test suites. This area has so far not been addressed in the field of EFC.

Also, while some phases in the process of electronic fee collection can be devised as technology independent, at least the phases of recognition and the identification of vehicles are strictly dependent on the technology used for tolling, so, in the specific case of ANPR, they depend on the ANPR technology.

Some regional standards (for example, UNI 10772) specify procedures for testing the optical and optical character recognition (OCR) capabilities of ANPR systems, but the process chain of EFC is much wider than that.

A study is needed to identify characteristics of image-based systems for tolling to be tested for conformance to specifications and to measure key performance indicators (KPIs).

It is recognized that image-based systems that are suitable for tolling can be used for other purposes. Although such systems are out of the scope of the present document, informative Annex A is provided with some examples and case studies.

Electronic fee collection — Image-based tolling systems — Measurable characteristics

1 Scope

This document analyses the processes of image-based systems to be used for tolling purposes, with the aim to identify their specific characteristics, and where these characteristics can be observed. The study intends to answer the following questions:

a) Which are the relevant characteristics of an image-based system used for electronic fee collection (EFC)?

b) How can these characteristics be specified?

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO/TS 17573-2, *Electronic fee collection — System architecture for vehicle related tolling — Part 2: Vocabulary*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO/TS 17573-2 and the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
automated number plate recognition
ANPR
technology to automatically read vehicle registration plates

Note 1 to entry: A vehicle registration plate typically contains the indicator or the code of the country that issued the vehicle registration plate.

Note 2 to entry: Optical character recognition techniques are typically part of the technology associated with automated number plate recognition.

[SOURCE: ISO 17573-2:2020, 3.18]

3.2
enforcement
means to identify and pursue violators of laws, regulations or rules

3.3
false negative
incorrect reporting of a failure when in reality it is a pass

[SOURCE: ISO/IEC TR 29119-11:2020, 3.1.34]

3.4
false positive
incorrect reporting of a pass when in reality it is a failure

[SOURCE: ISO/IEC TR 29119-11:2020, 3.1.35]

3.5
formally valid licence plate
licence plate that has been correctly identified as for the nationality of the vehicle, the characters and the numbers, and the associated format

3.6
free-flow tolling system
collection of tolls on toll roads without the use of physical toll barriers

3.7
constrained tolling system
collection of tolls on toll roads that impose restrictions (in road lanes or speeds, or both) on vehicles where tolls are collected

Note 1 to entry: This covers, among others, all toll booths and toll plazas based tolling systems.

3.8
true negative
correct reporting of a failure when it is a failure

[SOURCE: ISO/IEC TR 29119-11:2020, 3.1.82]

3.9
true positive
correct reporting of a pass when it is a pass

[SOURCE: ISO/IEC TR 29119-11:2020, 3.1.83]

4 Symbols and abbreviated terms

A_r association rate

A_{tp} number of correct ANPR results (true positives)

C_r classification rate

C_m number of correctly classified vehicles (true or semi-true positives)

D_{fp} number of detected false positives

D_{fn} number of detected false negatives

D_{nr}, detection of false negatives rate

D_{pr} detection of false positives rate

D_r detection efficiency

$Im_{secondary}$ ratio between the number of vehicles correctly identified by the secondary system and the total number of correctly identified vehicles by the primary and secondary systems

$Ip_{secondary}$ is the number of vehicles correctly identified only by the secondary system

ID_r identification rate

P_f number of formally identified licence plates

P_r number of identified licence plates corresponding to existing real identified vehicles, that combines the results of both the primary and the secondary systems

V_d is the number of detected vehicles

V_t number of passed vehicles

AI artificial intelligence

ANPR automatic number plate recognition

DSRC dedicated short range communication

EFC electronic fee collection

KPI key performance indicator

LP licence plate

LPN licence plate number

OCR optical character recognition

RSE roadside equipment

5 Framework and classifications of discrete tolling systems

5.1 General — Dimensions of the problem

This document considers the characteristics of tolling systems where tolling is based on a number of geographically fixed identification points where vehicle passages and characteristics of the vehicles are observed. This is in contrast to tolling systems where tolling is based on the continuous recognition of how long (in time or space) a vehicle has travelled in an area or how many times has it crossed borders between defined areas. The considered tolling systems are known as discrete tolling systems.

An initial classification of discrete tolling systems can be made based on the geometrical characteristics of the tolling points, by roughly dividing the systems into free-flow tolling systems and constrained tolling systems. Another dimension, that can have an impact on the system's performance is the presence of multiple tolling technologies (e.g. DSRC manual payments, etc.), and their relevance to the processes incorporated in the tolling system (e.g. process of toll calculation). These and other dimensions add to the physical characteristics (e.g. communication, optical or OCR capabilities) of the tolling devices to form the body of variables to be considered, measured, and ultimately tested, to evaluate the tolling system.

The characteristics of discrete tolling systems that are described in Clause 5 are independent of the technology that is used for tolling.

5.2 General to processes and functional variables

In the US Department of Transportation's classification of congestion pricing technologies,[3] the generic tolling process, independent of the used technologies, can be divided into 7 sub-processes, each one characterized by the set of variables.

The identified sub-processes are as follows (the order is not significant):

— Information and registration — This process is related to all communication aspects of both the tolling system towards its users (signs, barriers, etc.), and the users towards the system (plate registration, installation and personalization of OBE, etc.).

- Passage detection — This process recognizes a vehicle's passage. The process is highly influenced by the geometry of the identification points (free-flow, constrained, etc.).
- Vehicle identification — This process uniquely identifies a vehicle, e.g. by recognizing its licence plate, or by reading its OBE identifier. The process is dependent on the used technology. It can use the same technology as for the passage detection, or a different one.
- Classification — This process classifies an identified vehicle according to the toll regime vehicle classes. This process can be performed with the same technologies used for passage detection or vehicle identification.
- Verifications and reliability — Information collected by the above sub-processes can be verified by further independent processes to enhance its reliability.

EXAMPLE The passage of a vehicle, that is recognized and classified by means of a DSRC transaction, can be verified by reading its licence plate or by the recognition of its axles and dimensions by laser sensors.

- Payment — The payment process is generally independent of the technologies that are used to identify and classify vehicles. However, it can be the case that further evidence is necessary for payment of a toll. For example, it can be necessary that a picture of the licence plate, associated with the time and geographical coordinates of the passage, is associated with a DSRC transaction.
- Enforcement— Enforcement is often associated with a technology alternative to that used for tolling. A typical example is ANPR used to enforce a DSRC-based tolling system.

Not all the above listed sub-processes are necessarily always present in a tolling system. Also, the existence and execution of one sub-process can in some cases influence the behaviour of other sub-processes.

The above sub-processes are listed without any temporal ordering. Figure 1 depicts the sub-processes by outlining, in a grey rectangle, those that characterize a specific EFC system by the tolling technology used.

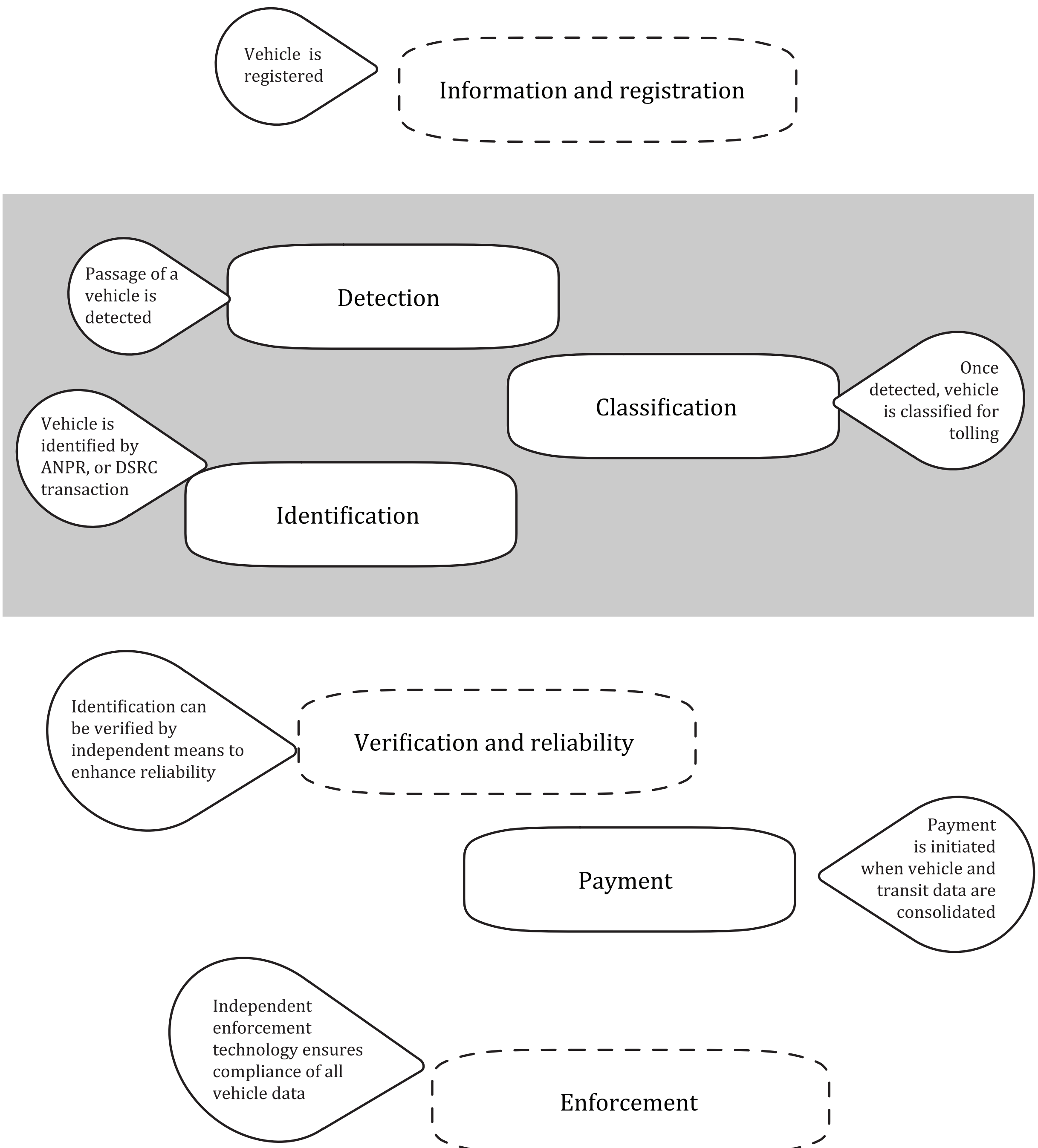

Figure 1 — EFC sub-processes

In Figure 1, two kinds of sub-processes are identified.

a) Core sub-processes, i.e. those sub-processes that are always present in any type of tolling system.

b) Auxiliary sub-processes, i.e. those sub-processes that can be present, e.g. to improve reliability (like “verification and reliability”), or must be present, e.g. due to local regulations (like “registration”).

Some EFC systems organize their processes in a sequential manner, as it is presented in Figure 2. Others feature some parallelism, as presented in Figure 3.

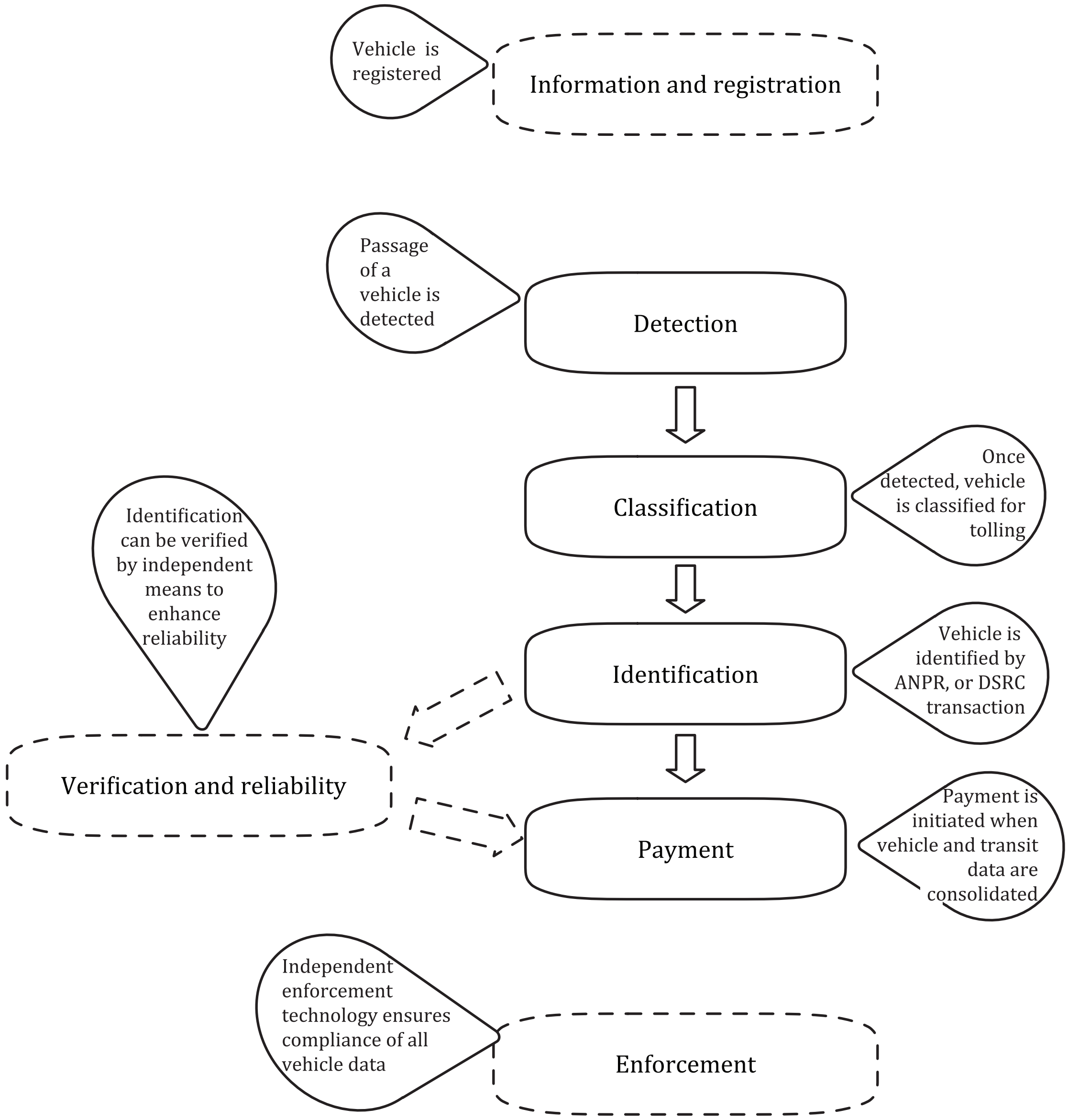

Figure 2 — Sequential ordering of EFC sub-processes

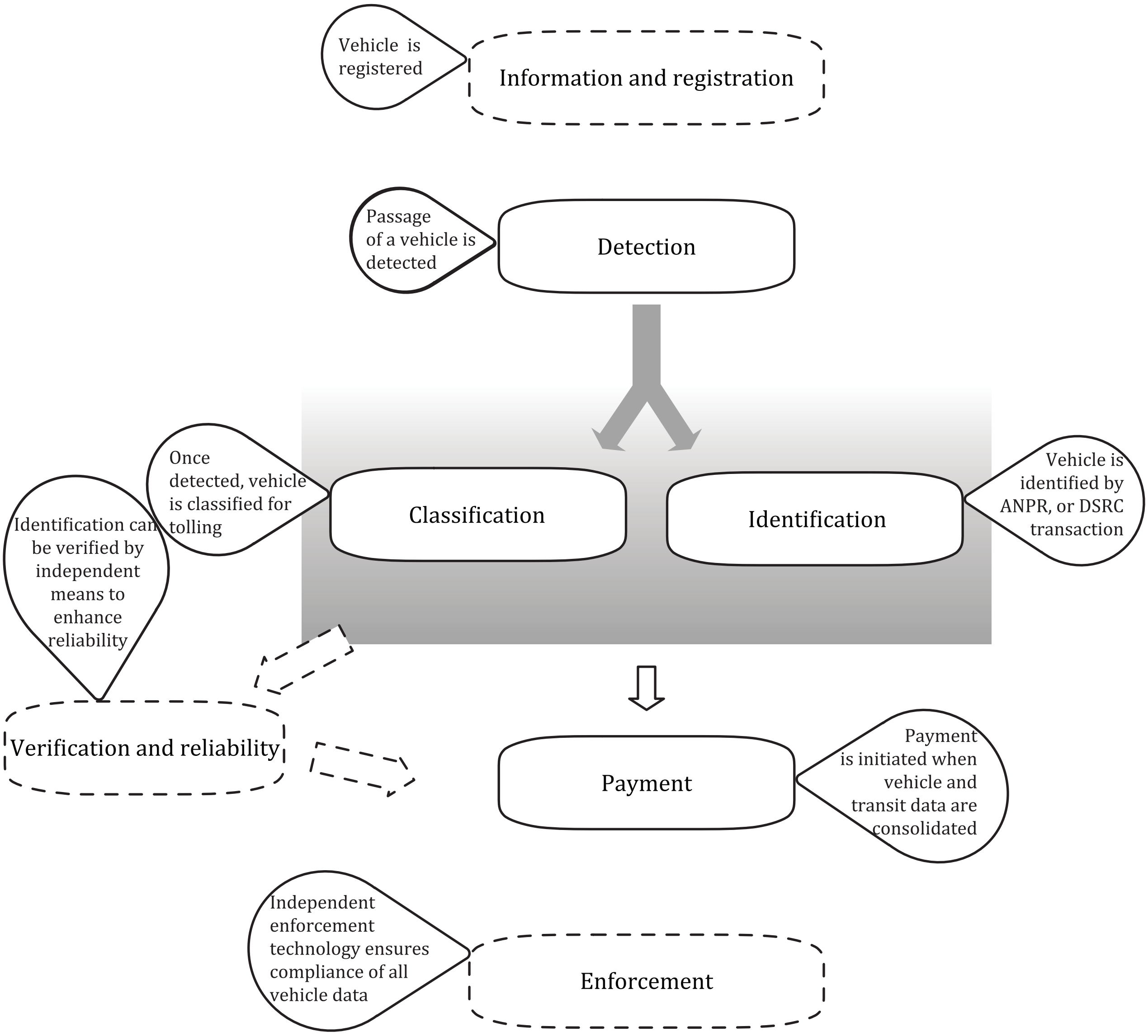

Figure 3 — Parallelism in EFC sub-processes

In all cases presented in Figure 3, it is assumed that, apart from a possible previous registration, the passage detection is the first sub-process that happens when an EFC system is triggered by the passage of a vehicle. However, it can happen that a single indivisible sub-process manages both detection, classification and identification of vehicles, as shown in Figure 4.

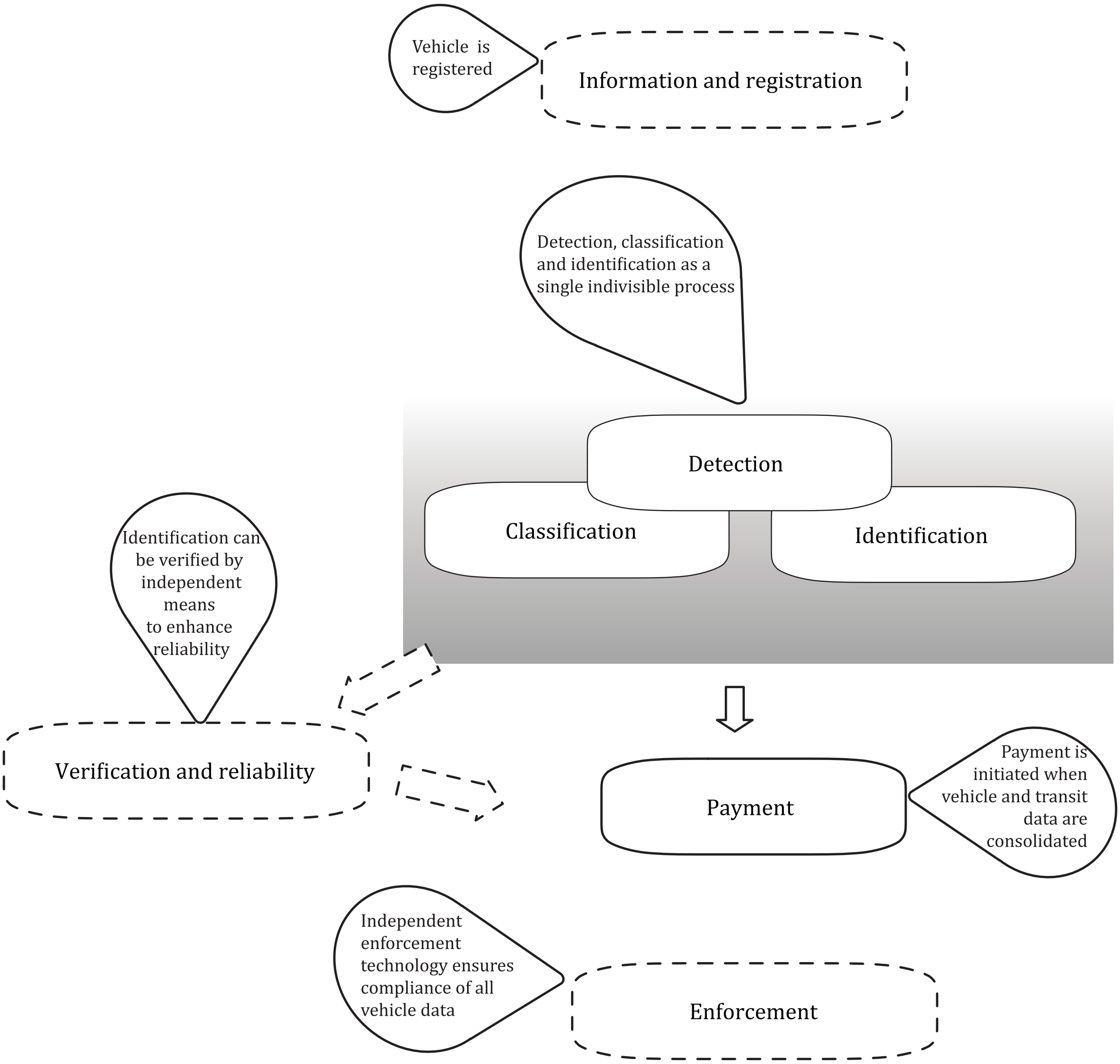

Figure 4 — Detection, classification and identification as a single sub-process

Ordering of sub-processes has implications on the definition of the functional variables that characterize any single sub-process, as shown in Clause 6.

Due to the different possible architectures of the processes implemented in any EFC system, specifying characteristics that can be tested for a system as a whole is very difficult. This document intends to identify the testable characteristics of each one of the above listed sub-processes independently of the other sub-processes.

All identified sub-processes can be described in terms of one or more characterizing variables. The set of all characterizing variables defines the tolling system dimensions and allows for identifying its performance indicators and critical aspects. Some variables are qualitative, others are not orthogonal with each other, so that the resulting analysis cannot be performed with pure numerical methods. More information on variables for image-based tolling systems is given in Clause 6.

Table 1 lists the characteristic variables associated to each sub-process. Note that the order of the rows in the table (i.e. the ordering of processes) is of no significance.

Table 1 — Tolling processes and associated variables

Sub-process or main functionality	Variables	Type	Range of values	Comments
Information and registration	Required registration	Qualitative	YES/NO	Registration improves vehicle identification.
Passage detection	System geometry	Qualitative	Example: Free-flow, slow and go, stop and go, etc.	System geometry affects identification, classification and detection.
	Detection technology	Qualitative	Examples: None, laser trigger, DSRC, camera, etc.	If detection is separate from identification, its efficiency, including false positives, must be considered.
	Detection rate	Quantitative	Percentage	Percentage of detected over passed vehicles.
	False positives	Quantitative	Percentage	Percentage of false positives over passed vehicles. Includes duplicates, like trailers counted as separate vehicles.
Classification	Separation from identification	Qualitative	YES/NO	If separate, classification rate is a useful measurement.
	Classification rate	Quantitative	Percentage	Percentage of correctly classified vehicles over detected vehicles.
	Tolling classes	Qualitative	Defined tolling classes	The more tolling classes, the more difficult it is to assign a correct classification.
Identification of vehicles	Technology	Qualitative	Examples: DSRC, ANPR, etc.	Used to evaluate separate systems with different technologies.
	Identification rate	Quantitative	Percentage	Percentage of automatically identified vehicles over correctly detected vehicles.
	Association rate	Quantitative	Percentage	Percentage of actually registered vehicles over formally identified vehicles.
Verifications and reliability	Verification system added value	Quantitative	0-Max	Additionally identified vehicles when a secondary system is used. It is a measure of the added value provided by a secondary system.
	Verification error	Quantitative	Percentage	Rate of incorrect vs. total verifications.
Payment	Payment type	Qualitative	— Immediate direct debit — Postponed direct debit — Postponed indirect debit — Etc.	
Enforcement	Presence of an enforcement system	Qualitative	YES/NO	
	Technology of enforcement system	Qualitative		

6 Variables in image-based tolling systems

6.1 General

ISO/TR 6026 intends to clarify some basic concepts for image-based EFC systems and to identify a number of possible standardization activities for those systems. The document contains a description of the tolling process but does not identify the variables that characterize image-based systems and that can be used to determine their critical aspects.

Of the variables used to characterize general EFC systems listed in Table 1, the following ones, both qualitative and quantitative, are relevant for classifying and measuring the efficiency of image-based systems:

— required registration (qualitative);

— system geometry (qualitative);

— detection technology (qualitative);

— detection rate (quantitative);

— classification rate (quantitative);

— tolling classes (qualitative);

— identification technology (qualitative);

— identification rate (quantitative);

— association rate (quantitative);

— verification system added value (quantitative);

— verification error (quantitative).

The qualitative variables of the list given in 6.1 can only be used to correctly classify and group together different image-based tolling systems into uniform categories. However, although some of these qualitative variables can influence the values of quantitative variables, their effects are rarely measurable, nor are they precisely predictable.

Subclauses 6.2 to 6.4 analyse only the quantitative variables. Most of these variables are independent from each other. In the case where they are dependent, that dependency is clearly indicated. The implications of using any of the following variables as KPIs, or as characteristics of a given system subject to test are also highlighted. Commonly, a reference system is used to determine the baseline data (also known as ground truth) when measuring KPIs.

An image-based tolling system is made by different components and its performance depends on specific conditions, both intrinsic (e.g. geometry and redundancy, presence of an external trigger, etc.) and external (e.g. weather conditions, general conditions of the circulating vehicles, lighting and latitude, etc.). Such integrated and composite nature makes it impossible to identify a generalized type of architecture for image-based tolling systems, thus rendering metrics measurement not feasible on overall system level.

6.2 Detection rate

6.2.1 Definition

The detection efficiency D_r of the detection sub-process is defined as the ratio between the number of detected vehicles and the number of vehicles that have passed through the detection point:

$$D_r = \frac{V_d}{V_t}$$

where:

V_d is the number of detected vehicles;

V_t is the number of passed vehicles.

Detection of vehicles can be performed by different technologies, which can be integrated in the image recognition system, or be separated from it. Some of detection technologies that are used by image-based tolling systems are (the list is not exhaustive):

— Laser based triggers — A laser scanner detects an object moving towards the detection point, and by that it starts the image recognition system.

— Radar based triggers — Same as for laser-based triggers, the difference being that incoming objects are recognized by a radar.

— Image recognition — The detection and recognition of incoming vehicles is performed by the same system.

Detection rate depends on several components and, at the same time, can be affected by specific conditions, both intrinsic and external.

This variable can be used as a KPI in a real system. In this case, implementation specificities are crucial to correctly assess the KPI, and a reasonable observation time, with respect to traffic conditions and with the desired precision is due. Also, a sufficiently accurate and reliable external system to count passing vehicles is needed to serve as a reference.

It can be the case that detections correspond to actual vehicles, or to objects that are not vehicles. Conversely, passed vehicles will possibly not be detected, or they can incorrectly be considered not subject to payment. Table 2 summarizes the various cases that can occur.

Table 2 — Result of image-based detections

Result of image-based detection	Description
True positive	A vehicle, being subject to toll payment, that has been correctly detected by the image-based detection functionality of the roadside equipment (RSE).
False positive	An object, not being a vehicle subject to toll payment, detected by the image-based detection functionality of the RSE as a vehicle, e.g. a big animal crossing the road, a trailer detected as a separate vehicle subject to toll payment or a moving shadow from a vehicle in the lane next to the actual lane.
True negative	An object, not being a vehicle subject to toll payment, detected by the image-based detection functionality of the RSE as an object not being a vehicle subject to toll payment.
False negative	A vehicle, being a vehicle subject to toll payment, that has not been detected by the image-based detection functionality of the RSE.

6.2.2 Detection of false positives rate

Detection of false positives rate D_{pr} is defined as the ratio between the number of detections of false positives (D_{fp}) and the number of passed vehicles (V_t). The variable describes the rate between the detected objects that were not a vehicle but detected as a vehicle, and the total number of vehicles that passed through the charging point.

This variable can be used as a KPI in a real system. In this case, implementation specificities are crucial to correctly assess the KPI, and a reasonable observation time, with respect to traffic conditions and with the desired precision is due. Also, a sufficiently accurate and reliable external system to count passing vehicles is needed to serve as a reference.

$$D_{\mathrm{pr}} = \frac{D_{\mathrm{fp}}}{V_{\mathrm{t}}}$$

where:

D_{fp} is the number of detected false positives;

V_{t} is the number of passed vehicles.

If this variable is used as a KPI indicator in a real system, an alternative detection system should be put in place to calculate or measure Vt, e.g. manual counting or continuous video and video analysis. In a test environment, Vt is a known quantity.

6.2.3 Detection of false negatives rate

Detection of false negatives rate, D_{nr}, is defined as the ratio between the number of detections of false negatives (D_{fn}) and the number of passed vehicles (V_{t}). The variable describes the rate between the objects that were vehicles subject to toll, but not detected as vehicles subject to toll and the total number of vehicles that have passed through the charging point.

This variable can be used as a KPI in a real system. In this case, implementation specificities are crucial to correctly assess the KPI, and a reasonable observation time, with respect to traffic conditions and with the desired precision is due. Also, a sufficiently accurate and reliable external system to count passing vehicles is needed to serve as a reference.

$$D_{\mathrm{nr}} = \frac{D_{\mathrm{fn}}}{V_{\mathrm{t}}}$$

where:

D_{fn} is the number of false negatives;

V_{t} is the number of passed vehicles.

If this variable is used as a KPI in a real system, an external detection system should be put in place to calculate or measure $V_{\mathrm{t},}$ e.g. manual counting or continuous video and video analysis. In a test environment, V_{t} is a known quantity.

6.3 Identification rate

6.3.1 Definition

The identification rate, indicated by ID_{r}, relates to the efficiency of the automatic plate identification process, as for extracting a correct ANPR result from the image(s) taken by cameras. A correct ANPR result ensures that an image of the front or rear of a vehicle includes a licence plate that fulfils the licence plate format requirements of the jurisdictional area where the vehicle is registered. This includes:

— correctly identifying the nationality of the vehicle;

— correctly identify all characters and numbers in the licence plate;

— matching the patterns of letters and numbers with the template of vehicle licence plate for the related jurisdictional area;

— complying with the jurisdictional area requirements for the positioning of the licence plate on the vehicle front or rear.

NOTE A lack of compliance with the positioning requirements does not necessarily exclude the result from being correctly identified but raises the awareness of the toll operator, enabling the toll operator to decide whether this will be handled as a correct or incorrect identification.

It is important to note that a formally valid licence plate number does not necessarily correspond to an “actual” registered vehicle. It only ensures that the format of the symbols, signs, characters, and digits as well as the format of the plate and its position on the front or rear of the vehicle comply with the relevant jurisdictional area regulations.

As in the case of detection, identification can possibly be subject to various error situations. Result of image-based identification is summarized in Table 3.

Table 3 — Result of image-based identification

Result of image-based identification	Description
True positive	A licence plate that has correctly been found to comply with the relevant jurisdictional area regulations concerning the format of the symbols, signs and characters, and digits, as well as the format of the plate and its position on the front or rear of the vehicle. The toll operator can choose whether the format of the plate and its position on the front or rear of the vehicle will be part of the requirements for the ANPR result being true positive.
False positive	A licence plate that has incorrectly been found to comply with the relevant jurisdictional area regulations concerning the format of the symbols, signs, characters, and digits as well as the format of the plate and its position on the front or rear of the vehicle. The toll operator can choose whether the format of the plate and its position on the front or rear of the vehicle will be part of the requirements for the ANPR result being false positive.
True negative	A licence plate that has correctly been found not to comply with the relevant jurisdictional area regulations concerning the format of the symbols, signs, characters, and digits as well as the format of the plate and its position on the front or rear of the vehicle. The toll operator can choose whether the format of the plate and its position on the front or rear of the vehicle will be part of the requirements for the ANPR result being true negative.
False negative	A licence plate that has incorrectly been found not to comply with the relevant jurisdictional area regulations concerning the format of the symbols, signs, characters, and digits as well as the format of the plate and its position on the front or rear of the vehicle. The toll operator can choose whether the format of the plate and its position on the front or rear of the vehicle will be part of the requirements for the ANPR result being false negative.

The order of the processes is not always the same (for example identification can precede or follow classification), to properly identify the identification rate the different cases must be examined.

When the vehicle detection process temporarily precedes the vehicle identification process, the calculation of the identification rate depends on the detection results, not on the number of passed vehicles. In this case, the correct ID_r result rate of the ANPR extracting process is defined as the ratio between correct ANPR results (true positives) and detected vehicles:

$$ID_r = \frac{A_{tp}}{V_d}$$

where:

A_{tp} is the number of correct ANPR results (true positives);

V_d is the number of detected vehicles.

The number of correct ANPR results ($ANPR_{tp}$) can possibly include the result of the format and position of the licence plate. Hence, whenever the ID_r of a system is given, it must be described as an ID_r with or without the format and position of the licence plate used as characteristics.

When the vehicle classification process also temporarily precedes the vehicle identification process, the calculation of the identification rate depends on the classification results, not on the number of detected vehicles. In this case, the correct result rate of the ANPR extracting process is defined as the ratio between correct ANPR results (true positives) and classified vehicles:

$$ID_r = \frac{A_{tp}}{V_c}$$

where:

A_{tp} is the number of correct ANPR results (true positives);

V_c is the number of classified vehicles.

When the vehicle identification process is combined with other processes like vehicle detection or vehicle classification, then the ID_r variable cannot be determined.

It is important to note that most vehicles (including vehicle combinations) carry more than one licence plate, usually two, positioned in the front and in the rear of the vehicle. The following cases can occur:

a) The system is able to identify two or more licence plates. Then, the following can happen:

   i) All identified licence plates are identical. The “identified licence plate” is known.

   ii) The identified licence plates differ. In this case, identification depends on local regulations.

   NOTE A secondary system can assist in determining the primary identification plate (see 6.6).

b) The system only reads one licence plate. That plate, if identified, will be subject to association with a registered vehicle (see 6.5).

6.3.2 ANPR result verification

A correct ANPR result identifies an image of the front or rear of a vehicle that includes a licence plate that fulfils the licence plate format requirements of the jurisdictional area where the vehicle is registered. However, it does not identify that the ANPR result is linked to a real vehicle and registered in a national vehicle database.

If the true positive ANPR result is used for collecting toll from the vehicle owner, it must be verified as a registered licence plate linked to a vehicle and its owner. This can be done online at the charging point (fixed point), e.g. by access lists managed by the RSE or by highspeed connection to a national vehicle database. It can also be done off-line by the RSE or a toll operator central system sending the image data to the relevant national vehicle database requesting the vehicle physical data and vehicle owner data.

Access to the relevant national database for verification of a licence plate for a foreign vehicle can be a cumbersome process and, in some cases, not possible.

An image of a fake or stolen licence plate can be extracted as a true positive outcome of the ANPR result but the vehicle with the fake or stolen licence plate does not have to be registered by a national authority. A fake licence plate that is a twin of a licence plate that will be extracted as a correct ANPR result used on a vehicle of the same make, model and colour as the original vehicle, will be difficult to identify as a false positive.

6.4 Classification rate

The classification of vehicles is essential in an EFC system to derive the toll amount and can be determined in various ways and with different technologies. In image-based tolling systems, classification can be associated with identification, for example, by recovering vehicle data by using the identified licence plate, or it can be done by a separate process and technology. Classification can be performed:

— at detection of a vehicle: some detection technologies are also able to classify the detected vehicles. For example, volumetric detectors can be sufficient in some tolling systems to classify vehicles. In this case, all correctly detected vehicles are also classified (not necessarily in a correct way);

— at identification of a vehicle: some identification systems can include an online retrieval of vehicle characteristics by its licence plate. In this case, all correctly identified vehicles are also classified (not necessarily in a correct way, for example, if the licence plate is fake or stolen);

— by an independent system.

Similarly to detection and identification, classification can incur in error situations, that are summarized in Table 4.

Table 4 — Result of classification

Result of classification	Description
True positive	A classification of a vehicle to a vehicle class used in the actual image-based tolling system based on the vehicle's correct identification (formally valid licence plate) and the vehicle characteristics documented in the vehicle licence. An operator of an image-based tolling system can accept a classification (semi-true positive) where the vehicles characteristics used for the classification are measured with a quality and deviation limits acceptable for the vehicle owners and operator, e.g. volumetric detectors.
False positive	A classification of a vehicle to a vehicle class used in the actual image-based tolling system based on the vehicle's incorrect identification, e.g. a fake licence plate.
True negative	n/a
False negative	n/a

The classification rate C_r is used to evaluate the classification system. When classification is performed independently of detection and identification, the classification rate C_r is used to evaluate the classification system, and it is defined as:

$$C_r = \frac{C_m}{V_t}$$

where:

C_m is the number of correctly classified vehicles (true or semi-true positives);

V_t is the number of passed vehicles.

This variable can be used as a KPI in a real system. In this case, implementation specificities are crucial to correctly assess the KPI, and a reasonable observation time, with respect to traffic conditions and with the desired precision is due. Also, a sufficiently accurate and reliable external system to count passing vehicles is required to serve as a reference.

In a test environment, V_t is a known quantity.

When classification is performed on identified vehicles (i.e. it uses the results of a previous identification process), then the classification rate C_r is defined as:

$$C_r = \frac{C_m}{V_d}$$

where:

C_m is the number of correctly classified vehicles (true or semi-true positives);

V_d is the number of detected vehicles.

6.5 Association of identified licence plates with registered vehicles

Not all plates that have been correctly read by the combined process of primary and secondary systems (see 6.6) necessarily correspond to actual vehicles. This happens for example if plates are faked or if a character has been incorrectly identified. This means that the process of associating an identified licence plate with a real vehicle and user is separated from the identification process as intended in 6.3. Verification of the correspondence of identified licence plates with actual registered vehicles is a process that involves interaction with external entities such as, for example, a national vehicle register.

Performance and efficiency of an external entity cannot be considered when evaluating a system's performance and efficiency. Consequently, although the way this feature is implemented in real products can have a great impact on the performance and efficacy of the overall EFC system, a variable associated with these characteristics cannot be used to evaluate the performance or the compliance of an image-based tolling system.

The association rate, A_r is defined as the ratio between the number of identified licence plates that correspond to existing vehicles and the number of formally identified licence plates:

$$A_r = \frac{P_r}{P_f}$$

where:

P_r is the number of identified licence plates corresponding to existing real identified vehicles, that combines the results of both the primary and the secondary systems (see 6.6);

P_f is the number of formally identified licence plates.

The process of association with actual vehicles can use different parameters to match the observed characteristics to registered vehicle properties, such as:

— LPN and nationality;

— make and model of the vehicle;

— colour of the vehicle.

The association rate is dependent on the way the verification is performed. If only the LPN and nationality is used for verification, there will be a higher number of false positives than if more parameters are used, as falsified plates will not be detected. If the make and model of the vehicle is included in the verification, fewer false positives can be expected. Possibly, the fewest false positives will be seen if also the colour of the vehicle is used, as the only false positives then will be where fake plates are fitted to the same model vehicle of the same colour as the one registered to that LPN. The association rate will also depend on how common the use of false plates is. For these reasons, the direct comparison of the association rate between systems will not always be valid.

6.6 Verification system added value and verification error

A number of existing and planned image-based EFC systems include an additional component to improve the overall efficiency, which in literature is often called "secondary system", as opposed to the primary (pure plate recognition) one. For example, plates that the image-based system is unable to identify with reasonable certainty can be delivered to a group of human operators, or to a more complex, perhaps AI-driven, and more expensive, OCR. Apart from the inevitable error rate of this secondary system, it is important to consider its "impact" in the global efficiency of the combined EFC system (primary and secondary), in terms of the percentage of added value to the primary system. This added value, $Im_{secondary}$, is defined as the ratio between the number of vehicles correctly identified by the secondary system and the total number of correctly identified vehicles by the primary and secondary systems:

$$Im_{\text{secondary}} = \frac{Ip_{\text{secondary}}}{Ip_{\text{secondary}} + P_{\text{r}}}$$

where:

$Ip_{\text{secondary}}$ is the number of vehicles correctly identified only by the secondary system;

P_{r} is the number of vehicles correctly identified by the primary system.

The added value of a verification system and its verification errors are factors that are included here only for completeness of the analysis, and have no impact on the testing or verification of the image-based EFC system.

7 Testing and performance evaluation

7.1 Generalities

All sub-process characterizing variables that have been identified in Clause 6 can be calculated as the input and output of the related sub-process can be measured. This is not true in all real implemented systems, as often sub-processes are grouped in not divisible units.

Also, while some sub-processes, or combinations thereof, can be isolated, so that their characteristic variables can be measured in, for example, a conformance test laboratory, others may be strictly dependent on the EFC system implementation.

— The identification rate (see 6.3) can be measured in a testing laboratory if the OCR subsystem can be separately installed in the testing lab so that its input and outputs can be clearly identified. In this case, tests to verify compliance of that subsystem to a regulation can be performed.

— The detection rate (see 6.2), even if its related sub-process main components can in some cases be separately installed in a testing lab, only has meaning when measured *in loco*, i.e. where the actual EFC system is installed. In this case, the meaning of the value of this variable only makes sense as a KPI.

7.2 Suitability of characteristic variables

The characterizing variables specified in Clause 6 can be suitable for assessing the compliance of one sub-process to a given specification, or to evaluate its adherence to specified KPIs, or both, according to various conditions, as given in Clause 6. Table 5 summarizes the suggested usage of each of the previously identified variables for both the compliance test in a lab and the evaluation of KPI.

Table 5 — Suitability of characteristics variables

Variable	Definition	Compliance test lab		KPI	
		Suitability	Conditions	Suitability	Conditions
Detection rate	$D_r = \frac{V_r}{V_t}$	No		Yes	Additional trusted detection system available
Detection of false positives rate	$D_{pr} = \frac{D_{fp}}{V_t}$	No		Yes	Additional trusted detection system available
Detection of false negatives rate	$D_{nr} = \frac{D_{fn}}{V_t}$	No		Yes	Additional trusted detection system available
Identification rate when detection precedes identification	$ID_r = \frac{A_{tp}}{V_d}$	Yes	OCR separately testable	Yes	OCR separately testable
Identification rate when classification precedes identification	$ID_r = \frac{A_{tp}}{V_c}$	Yes	OCR separately testable	Yes	OCR separately testable
Classification rate when independent of detection and identification	$C_r = \frac{C_m}{V_t}$	Yes	Classification system separately testable	Yes	Additional trusted detection system available
Classification rate when classification happens after identification	$C_r = \frac{C_m}{V_r}$	Yes	Classification system separately testable	Yes	Additional trusted identification system available
Association rate	$As_r = \frac{P_r}{P_f}$	No		No	

Annex A
(informative)

Image-based systems in contexts different from EFC

Image-based vehicle detections systems have become ubiquitous, observing vehicles for traffic management, zoning, disaster management, freight control, logistics, traffic rule transgression, law enforcement, vehicle access control and vehicle tracking (typically within zones like a factory complex or an airport), for example. Often these systems are used in conjunction with other sensors, like location detectors, presence detectors, acoustic sensors, vibration sensors and weight sensors.

The purpose of image-based toll systems is to identify the vehicle as presented by the vehicle licence plate to facilitate the toll payment. Misidentification and counterfeits are typically detected in downstream systems which raise an intervention request.

In general, an image-based system performs any combination of:

a) vehicle presence detection;

b) vehicle classification;

c) vehicle identification based on the vehicle licence plate;

d) vehicle identity confirmation based on other sensor data and/or external vehicle identity information.

An image-based vehicle detection can be a recording for post processing of the detection application or trigger for an immediate action, like opening a gate, creating a legal bundle for prosecution, or calling for an immediate intervention by alerting an enforcement vehicle.

Image based tolling typically uses the first three items of the list above. It is fair to state that current image detection technologies cannot detect counterfeit vehicle licence plates, nor are aware that they made a mistake. Therefore, a vehicle fitted with a counterfeit or tampered plate effectively becomes invisible to applications which process the vehicle identity downstream. It is also well-known that plates are tampered with, with the aim to render them unreadable, or to trigger the image detector to provide incorrect result. Such vehicles can only be processed (i.e. filtered out) by immediate intervention which becomes exponentially more effective, when independent vehicle identification applications operate harmoniously and share information. The metrics presented in this document enable a harmonized methodology for interoperability.

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