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SERIES L: ENVIRONMENT AND ICTS, CLIMATE CHANGE, E-WASTE, ENERGY EFFICIENCY; CONSTRUCTION, INSTALLATION AND PROTECTION OF CABLES AND OTHER ELEMENTS OF OUTSIDE PLANT

E-waste and circular economy

Effects of information and communication technology-enabled autonomy on vehicles longevity and waste creation

Recommendation ITU-T L.1040

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ITU-T L-SERIES RECOMMENDATIONS

ENVIRONMENT AND ICTS, CLIMATE CHANGE, E-WASTE, ENERGY EFFICIENCY; CONSTRUCTION, INSTALLATION AND PROTECTION OF CABLES AND OTHER ELEMENTS OF OUTSIDE PLANT

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Recommendation ITU-T L.1040

Effects of information and communication technology-enabled autonomy on vehicles longevity and waste creation

Summary

Recommendation ITU-T L.1040 establishes guidelines and requirements for information and communication technology original equipment manufacturer vendors providing equipment to autonomous vehicles aiming to reduce the amount of future e-waste.

Recommendation ITU-T L.1040 analyses the e-waste risks and other sustainability indicators of autonomous vehicles and proposes how these potential challenges can be mitigated.

Recommendation ITU-T L.1040 utilizes information compiled from stakeholders that can provide good insights into the specified potential challenge.

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Table of Contents

Introduction

Longevity (durability) is the most important aspect for lowering environmental impact in a circular economy. At the same time ~80 million new automotive vehicles – electric and others – are sold annually and ~1 billion are out on the streets. Other vehicles, like fleets of large commercial trucks and aircraft, account for ~250 million and ~25 000, respectively. All automotive autonomous vehicles (AVs) contain a significant value – and amount – of information and communication technology (ICT). The mass of ICT hardware (HW) per vehicle is expected to rise from ~20 kg to ~60 kg for AVss defined by software (SW) and other e-vehicles. The trend is that several (most) AVs (battery electric vehicles (BEVs) and others) will be equipped with ICT solutions that make them autonomous, i.e., they can "drive by themselves". There is a clear risk that the average lifetime of SW-defined AVs will be much shorter than for ordinary internal combustion engine vehicles (ICEVs). This could lead to additional e-waste creation.

There are several reasons why SW-defined AVs – usually BEVs – may have shorter lifetimes than conventional. In general, similar to consumer ICT goods, AV may involve high usability and frequent updates of both new models and SW. AVs and BEVs usually refer to next generation vehicles using more functionality than typical ICEVs.

High usability results in high kilometrage, which affects the lifespan of the vehicle. Compared to ICEVs, AVs and BEVs may provide an easier, less costly, and more comfortable driving experience. Therefore, private usage daily driving may increase sharply, leading to more wear.

As in the consumer ICT industry, new technologies will likely accelerate the innovation of new models in the AV industry. Moreover, the design and launch time of AVs may be short. Additionally, consumers may be encouraged to buy new AV models more often than ICEVs, and this might increase the amounts of ICT-related AV waste. It has been estimated that 10-12 years elapse before ICEVs are scrapped but only 4 years for AVs/BEVs. AVs or BEVs may have three times the amount (~60 kg/unit) of ICT HW as current ICEVs (~20 kg/ICEV unit).

The number of BEVs and fuel cell vehicles put on the market is expected to increase more rapidly from 2020 to 2030 or 2040 than between 2010 and 2020. In 2040, this may generate an additional 2 to 4 Mt of AV or BEV ICT waste and ~8 Mt battery waste. The model used to estimate certain waste and greenhouse gases from production of vehicles globally is discussed in Appendix I.

SW upgrades may overtake those of HW. AVs rely highly on the control system, and like technology upgrades, those for SW may be required in a shorter period, while vehicle HW – such as components, parts, and sensors – cannot be replaced as easily or as quickly.

Recommendation ITU-T L.1040

Effects of information and communication technology-enabled autonomy on vehicles longevity and waste creation

1 Scope

This Recommendation establishes guidelines and requirements for information and communication technology original equipment manufacturer vendors providing equipment to autonomous vehicles aiming to reduce the amount of future e-waste.

This Recommendation analyses the e-waste risks and other sustainability indicators of autonomous vehicles and proposes how these potential challenges can be mitigated.

This Recommendation utilises information compiled from stakeholders that can provide good insights into the specified potential challenge.

This Recommendation contains an analysis of the longevity of autonomous vehicle (AVs). It is plausible that the lifetime of information and communication technology (ICT) components inside AVs could be shorter than manually driven internal combustion engine vehicles (ICEVs). If so, additional e-waste – and other waste – may be created. The Recommendation also considers the possible solutions to the problems arising from waste creation caused by ICT enabled AVs. The Recommendation contains a guide for best practice design for longevity of AVs at a global level.

2 References

The following ITU-T Recommendations and other references contain provisions which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published. The reference to a document within this Recommendation does not give it, as a stand-alone document, the status of a Recommendation.

[ITU-T L.1410] Recommendation ITU-T L.1410 (2014), *Methodology for environmental life cycle assessments of information and communication technology goods, networks and services*.

3 Terms and definitions

3.1 Terms defined elsewhere

This Recommendation uses the following terms defined elsewhere:

3.1.1 autonomous vehicle [b-AR]: Vehicle equipped with an automated driving system that can drive the vehicle for any duration of time without the active physical control or monitoring of a human operator.

3.1.2 battery electric vehicle [b-LI]: Vehicle that operates exclusively on electrical energy from an off-board source that is stored in the vehicle's batteries, and produces zero tailpipe emissions or pollution when stationary or operating.

3.1.3 fuel cell vehicle [b-UNECE]: Vehicle with a fuel cell and an electric machine as propulsion energy converters.

3.1.4 hazardous substance [b-ISO/TS 22002-5]: Solid, liquid or gas that is radioactive, flammable, explosive, corrosive, oxidizing, asphyxiating, pathogenic or allergenic, including, but not restricted to, detergents, sanitizers, pest control chemicals, lubricants, paints, processing aids and biochemical additives, which, if used or handled incorrectly or in increased dosage, could cause harm to the handler and/or consumer

3.2 Terms defined in this Recommendation

This Recommendation defines the following term:

3.2.1 software-defined autonomous vehicle: Autonomous vehicle whose intelligence is largely delivered through software.

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

AV Autonomous Vehicle

BEV Battery Electric Vehicle

GHG Greenhouse Gas

HW Hardware

ICT Information and Communication Technology

ICEV Internal Combustion Engine Vehicle

OS Operating System

SW Software

5 Conventions

None.

6 Autonomous vehicles and e-waste

Clauses 6.1 to 6.8 list several guidelines and requirements that may decrease eco-impacts, detoxify and reduce e-waste related to ICT hardware (HW) in AVs or battery electric vehicles (BEVs).

6.1 Hazardous substances

- Manufacturers shall ensure that the ICT HW of AVs at least be in harmony with the *End of life vehicle directive* (available from [b-EC ELV]) and its revision.
- Manufacturers should avoid the use of hazardous substances.
- Manufacturers should encourage the reduction of number of chemical categories used in production.

NOTE 1 – The material composition is relevant for fire safety aspects of AVs/BEVs.

NOTE 2 – Ever higher voltage is the general trend for batteries. Higher voltage may increase the risk of fire and emissions of hazardous substances.

6.2 Eco-friendly materials and recyclable materials

- Manufacturers should use eco-friendly and recyclable materials for ICT HW in AVs.
- Manufacturers should develop eco-friendly and recyclable materials or parts for ICT HW in AVs.
- Manufacturers should use the simplest possible painting for ICT HW in AVs where applicable.

6.3 Standardized model and modular design

- The degree of modularity (generic building block design) should be determined for ICT HW in AVs.

6.4 Standardized essential components

- All components used shall conform to criteria in international standards, e.g., on safety and performance.

6.5 Reparability and maintainability

- The degree of reparability should be determined for ICT HW in AVs.
- The degree of maintainability should be determined for ICT HW in AVs.

6.6 Remanufacturing

- The ability of ICT HW for AVs to be remanufactured should be maximized.
- The degree of ability to be remanufactured should be determined for ICT HW for AVs.
- The degree of ability of parts and components to be reused should be determined for ICT HW for AVs.

6.7 Replaceable software

- The degree of replaceable and harmonized operating system (OS) (in the microcontroller HW) should be determined for ICT HW in AVs.

NOTE – Refers to the ability to replace the microcontroller.

- The OS should be developed from common principles of modularity and scalability.
- The degree of compatibility of all OS with all current AV models, and *vice versa*, should be determined for ICT HW in AVs.
- The degree of compatibility of all OSs of customized software (SW) applications with all models, should be determined for ICT HW in AVs.
- The degree of SW change burden on HW change should be determined for ICT HW in AVs.
- ICT HW should be future proof and backward compatible.

6.8 Upgrade compatibility

- SW updates should be compatible with current ICT HW.
- HW updates should be compatible with current SW.

6.9 Greenhouse gas emissions

- Manufacturers should quantify the amount of greenhouse gas (GHG) emissions with life cycle assessment (LCA) from upstream, distribution, use and end-of-first life according to [ITU-T L.1410] for ICT HW in AVs.

7 Assessing the longevity of the ICT components of an autonomous vehicle

Clauses 7.1 to 7.4 list several guidelines that may increase the longevity of ICT HW in AVs.

7.1 Usage and mileage

- Manufacturers should set the minimum kilometrage and lifespan for AVs.
- Manufacturers should commit resources to maintain ICT HW in AVs.

7.2 Remote monitoring

- Manufacturers should provide remote monitoring of AV usage and assess AV usage time and lifespan.

7.3 Critical part

- The lifespan of critical (priority) parts should be assessed or verified according to international standards.

7.4 Test and verification

- Moderate or frequent testing and verification should be considered for AV condition and lifespan.

Annex A

Scorecard for guidelines and requirements evaluation

(This annex forms an integral part of this Recommendation.)

Table A.1 – Scorecard for guidelines and requirements for evaluation

Guideline or requirements	Clause	Met	Unmet
Ensuring ICT HW in AVs is at least in harmony with the ELV directive. (requirement)	6.1	Yes/No	Yes/No
Avoidance of hazardous substance use.	6.1	Yes/No	Yes/No
Encouragement of the reduction of number of chemical categories used in production.	6.1	Yes/No	Yes/No
Use of eco-friendly and recyclable materials for ICT HW in AVs.	6.2	Yes/No	Yes/No
Development of eco-friendly and recyclable materials or parts for ICT HW in AVs.	6.2	Yes/No	Yes/No
Use of the simplest possible painting for ICT HW in AVs where applicable.	6.2	Yes/No	Yes/No
Determination of the degree of modularity (generic building block design) for ICT HW in AVs.	6.3	Yes/No	Yes/No
Conformity of all components used to criteria in international standards, e.g., on safety and performance. (requirement)	6.4	Yes/No	Yes/No
Determination of the degree of reparability for ICT HW in AVs.	6.5	Yes/No	Yes/No
Determination of the degree of maintainability for ICT HW in AVs.	6.5	Yes/No	Yes/No

Table A.1 – Scorecard for guidelines and requirements for evaluation

Guideline or requirements	Clause	Met	Unmet
Maximization of the ability of ICT HW in AVs to be remanufactured.	6.6	Yes/No	Yes/No
Determination of the degree of ability to be remanufactured for ICT HW in AVs.	6.6	Yes/No	Yes/No
Determination of the degree of ability of parts and components to be reused for ICT HW in AVs.	6.6	Yes/No	Yes/No
Determination of the degree of replaceable and harmonized OS (in the microcontroller HW) for ICT HW in AVs.	6.7	Yes/No	Yes/No
Development of the OS from common principles of modularity and scalability.	6.7	Yes/No	Yes/No
Determination of the degree of compatibility of all OSs with all current AV models, and *vice versa*, for ICT HW in AVs.	6.7	Yes/No	Yes/No
Determination of the degree of compatibility of all OSs of customized SW applications with all models, for ICT HW in AVs.	6.7	Yes/No	Yes/No
Determination of the degree of SW change burden on hardware change for ICT HW in AVs.	6.7	Yes/No	Yes/No
Ensuring that ICT HW is future proof and backward compatible.	6.7	Yes/No	Yes/No
Ensuring that SW updates are compatible with current ICT HW.	6.8	Yes/No	Yes/No

Table A.1 – Scorecard for guidelines and requirements for evaluation

Guideline or requirements	Clause	Met	Unmet
Ensuring that hardware updates are compatible with current SW.	6.8	Yes/No	Yes/No
Quantification of the amount of GHG emissions by LCA from upstream, distribution, use and end-of-first life according to [ITU-T L.1410] for ICT HW in AVs.	6.9	Yes/No	Yes/No
Setting the minimum kilometrage and lifespan for AVs.	7.1	Yes/No	Yes/No
Commitment of resources to maintain ICT HW in AVs.	7.1	Yes/No	Yes/No
Provision of remote monitoring for AV usage and assessment of the usage time and lifespan.	7.2	Yes/No	Yes/No
Assessment or verification of the lifespan of critical (priority) parts according to international standards.	7.3	Yes/No	Yes/No
Consideration of moderate or frequent testing and verification of AV condition and lifespan.	7.4	Yes/No	Yes/No

Appendix I

Model for estimating ICT and battery waste generation from vehicles including autonomous and battery electric vehicles

(This appendix does not form an integral part of this Recommendation.)

This appendix outlines the schematics and main assumptions in a model used to estimate annual global ICT and battery waste generation as a result of variable lifespan of AVs or BEVs.

Similarly to Equation 5 of [b-Islam], as far as annual ICT HW waste generation, this model for calculating total mass of ICT HW from AV vehicles waste in year 2010, etc. features in principle:

- "year"
- "category of AV vehicle that contains ICT HW, which becomes e-waste"
- "total number of units of category of AV vehicle which contains ICT HW sold in year 2010, etc."
- "net mass of the ICT HW in the AV vehicle in the year 2010, etc."
- "failure rate of AV vehicle that contains ICT HW since year 2010".

ICEV cars are assumed to decline from 95% market share of those sold in 2010 to 41% in 2040.

Hybrid, BEV ("Light EV") and FCEV vehicles are assumed to increase from 5% market share in 2010 to 58% in 2040.

ICEV trucks are assumed to decline from 100% market share of trucks sold in 2010 to 66% in 2040.

AV or BEV ("Heavy EV") and FCEV trucks are assumed to increase from ~0% market share of trucks sold in 2010 to 34% in 2040.

If the lifespan of ICT HW in AVs or BEVs is set to 4 years, the first e-waste is generated in 2013.

If the lifespan of the ICT HW in AVs or BEVs is set to 8 years, the first e-waste is delayed and generated in 2017. The more AVs or BEVs that are produced, the more e-waste is potentially generated.

If the lifespan of the battery HW in AVs or BEVs is set to 6 years, the first e-waste is generated in 2015. However, p. 4 of [b-Curt] argues that BEV batteries first lifespan is 10-15 years and may have a second life of 10 years.

Traditional ICEV car assumptions

20 kg ICT HW and 25 kg batteries per vehicle.

Hybrid car assumptions

25 kg ICT HW and 40 kg batteries per vehicle.

AV or BEV car assumptions

60 kg ICT HW per vehicle and 240 kg battery per vehicle.

FCEV car assumptions

60 kg ICT HW per vehicle. Fuel cell waste is not included.

Traditional ICEV truck assumptions

40 kg ICT HW and 100 kg batteries per truck.

AV ICEV truck assumptions

100 kg ICT HW per vehicle.

FCEV truck assumptions

100 kg ICT HW per vehicle. Fuel cell waste is not included.

Electric truck assumptions

100 kg ICT HW and 400 kg battery per vehicle.

Carbon

From 2010 to 2040 the kilogram CO_2-equivalents per kilogram of ICT HW is assumed to be on average around 300 kg/kg.

Table I.1 shows the key results for e-waste generation as a result of introducing AVs.

Table I.1 – Key results for e-waste and battery waste generation and greenhouse gas emissions for vehicles 2010 to 2040

	2010	2015	2020	2025	2030	2035	2040
E-waste							
1) E-waste from all vehicles, 8 year lifetime of ICT (Mt)			2.5	2.9	3.0	4.1	5.8
1.1) E-waste from AVs or BEVs, 8 year lifetime of ICT (Mt)			0.005	0.082	0.23	0.78	2.1
2) E-waste from all vehicles, 4 years lifetime of ICT (Mt)		2.4	2.8	2.9	3.8	5.4	7.6
2.1) E-waste from AVs or BEVs, 4 year lifetime of ICT (Mt)		0.002 4	0.067	0.18	0.63	1.8	3.7
2.2) E-waste from AV ICEV trucks, 4 year lifetime of ICT HW (Mt)				0.012	0.042	0.014	0.026
Battery waste							
6) Battery waste from all vehicles, 6 year lifetime of battery (Mt)		3.9	4.5	4.8	6.4	9.6	15
7) Battery waste from all kinds of AVs or BEVs, 6 year lifetime of battery (Mt)		0.001 8	0.063	0.37	1.2	3.6	8.3
Greenhouse gas emissions							
8) GHG from all vehicles production (Mt CO_2-equivalents)	1 400	1 600	1 500	1 700	2 000	2 300	2 700
9) ICT HW GHG from AV or BEV production (Mt CO_2-equivalents)	0.14	4.7	28	110	380	830	1 700
10) ICT sector GHG (Mt CO_2-equivalents)	1 100	1 100	1 100	1 100	1 700	2 100	2 600

As shown in Table A.1, the proportion of AV or BEV ICT hardware production-related GHGs – of ICT sector GHGs – in 2020, 2030 and 2040 will be around 3%, 22% and 64%, respectively. ICT sector GHG levels for 2035 and 2040 are extrapolated from [b-Andrae] estimations from 2019 to 2030.

GHGs produced by AV or BEV ICT HW as a fraction of total vehicle production is projected to increase towards 2040.

ICT HW waste from emerging AVs or BEVs of the total ICT HW vehicle waste is projected to increase towards 2040. The trends are similar for battery vehicle waste.

Page 5 of [b-Melin] estimates that light EV and heavy EV will generate some 0.075, 0.3 and 1.4 Mt lithium-ion batteries for recycling in 2020, 2025 and 2030, respectively. These numbers are quite close to those in row 7) of Table A.1, suggesting that the present model makes sense.

Another finding is that this model estimates 1.55 million AV or BEV sales in 2020. For 2020, this fits rather well with [b-IEA], which reckons 2.8 million EV placed on the market. Moreover [b-InsideEVs] indicates that the total battery market in 2020 was 142.8 GWh, Then Table 1 of [b-Zheng] estimates around 30 kW h battery capacity per BEV, leading to 4.76 million (see Note) AV or BEV sales in 2020. The 4.76 million figure is comparable to this model's forecast for 2020 of 6.22 million hybrid (4.66 million) battery and plug.im electric vehicles (1.55 million).

NOTE – 142.8 GW h amount for light EV divided by 30 kWh per light EV.

It also aligns with the prediction in Figure 1 of [b-di Paolo Emilio] of 2% plug in hybrid and EV of all light vehicles put on the market.

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