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ANALYSING THE CONDITIONS OF ROAD ASSETS WITH A NETWORK THINKING

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Abstract

Road transport is indispensable and requires improvements. The current road asset maintenance practice often treats defects as isolated entities and guides follow-up actions in fragmented documentation. Most of the previous research tended to focus on limited types of road assets, which did not cover defects across different types or consider holistically causes and repair strategies.

This research explores relationships between five classes of information, summarizing various road objects into 66 assets, 48 defects, 28 repairs, 27 causes and 39 preventative treatments. Relationships in the network of road asset conditions are built by breaking paragraphs and descriptions of maintenance guidance in the United Kingdom into class-to-class relationships, checked and supplemented by standards from 8 overseas jurisdictions in 4 countries/regions. The network merges segregated road asset failures into a comprehensive network, which contributes to laying the ground rules in automating road maintenance and acts as a precursor to risk and reliability analyses for asset management.

Introduction

Road infrastructure is indispensable in our daily lives. Its maintenance is expensive but could only maintain roads in a serviceable condition. Despite a capital expenditure of £5bn in 2019/20 in the UK (Department for Transport, 2021), the percentage of trunk roads requiring further investigation had shown stagnant improvement over the years. This problem is significant because to meet targets of zero fatality, zero carbon and customer satisfaction on the Strategic Road Network by 2040-50 (National Highways, 2021c, pp. 6-7), the road infrastructure would require an aggressive step change. This step change can be brought by digitization, where its success will significantly increase the frequency and quality of road inspections, thereby majorly improving road conditions.

This research aims to address the societal problem of digitising road maintenance by studying the conditions of road assets as a network. This paper defines **road assets** to include a broad range of objects on roads, which are captured in the data dictionary in Part 3 of the Asset Data Management Manual (National Highways, 2021a) and categorised by previous researchers detailed in later sections. **Conditions** refer to risks, defects and potential defects to the road assets, typically recorded in codes of practice, guidance documents and inspection manuals. These conditions, their causes and consequent corrective and preventative actions will be represented as individual vertices in a **network** and connected by sets of linkages, modelling the complex real-world system of road defect relationships (Bondy et al., 1976). These definitions confine the scope of road defect relationships to be found in the state of practice.

The current state of practice records recommended maintenance actions and assessment methods of road conditions in the documentation. A hierarchy of documentation is available to provide guidance on road defects and their relationships with corrective and preventative actions. Documents range from regulations at the national level to inspection manuals by local authorities and codes of practice by professional institutions, exampled in Table I. Following the guidelines prescribed in these documents, road maintenance authorities adopt various methods and indicators to monitor the performance of roads (Cambridge Economic Policy Associates Ltd & TRL Ltd, 2018). These indicators may be inputted into pavement management systems to assist road maintenance authorities with deterioration predictions, visualisation and scheduling (Mikhail, 2020). After assessing the indicators, authorities typically aggregate road sections for maintenance planning and apply the most critical repair needed to the entire aggregated road section (Poppitt & Neshvadian, 2018). The implementation may be encouraged by financial (dis)incentives (Cambridge Economic Policy Associates Ltd & TRL Ltd, 2018).

A review of the current state of practice reveals a gap in that defects of road assets, their causations and recommended actions are often disconnected when they are recorded in separate documentation. The conditions of roads are either assessed by aggregated indices on the pavements or by qualitative inspection findings performed at a generic timeframe (National Highways, 2021b) on assets outside the pavement. These shortfalls potentially eliminate viable options in maintenance planning or lead to piecemeal solutions that treat the symptoms but not the underlying causes.

This research aims to make the following contributions:

- Create a comprehensive network of conditions by connecting segregated defects of road assets with their causations and recommended actions.

- The network provides viable options for planning maintenance activities at the system level. The diagnoses of underlying causes also improve the understanding of why road assets fail.

The paper first addresses the societal problem and illustrates the state of practice in road maintenance. After exploring the state of research in road asset management and maintenance, the author identifies the gaps in knowledge and proposes a novel approach to address the problem. The paper progresses with the results of networks of conditions of road assets and concludes the authors' contributions.

Table 1: Example documentation in the referenced hierarchy

Level in hierarchy	Example Documentations
National	Design Manual for Roads and Bridges, Traffic Signs Manual, Inspection Manual for Highway Structures, Local Transport Note
Local authorities	Inspection and maintenance guidance, asset management plan
Professional institutes and interest groups	Codes of practice and guidelines, publications on focused research (e.g. CIRIA and BEAMA)
Standards organizations	Standards
Transport Research Laboratory	Traffic Advisory Leaflets on the research of specific road furniture
Maintenance companies	Specifications and brochures on asset repairs

State of Research

Studies on road assets at the component level

Some research aimed at the breadth of road assets by proposing categories to group all major road assets. The road maintenance authority usually issued a full list of road asset types applicable under its jurisdiction, such as the data dictionary in the Asset Data Management Manual issued by the National Highways of the UK (National Highways, 2021a). Researchers adopted more concise categorisations for more tractable failure analyses (Orugbo et al., 2015) and discussions on the general operation and maintenance of road networks (Tang & Zhang, 2021, Sec. 4.1.1). Previous researchers from the University of Cambridge prepared a mind map categorizing roadside or on-road assets in 19 asset categories (Ding & Brilakis, 2023). Categorisation of road assets would benefit the identification of failures and subsequent causal analyses.

Other research on road assets explored defects of selected assets. Different from routine maintenance manuals that gave instructions to repair actions, this research on specific road assets tended to include findings from case studies and provide more in-depth technical explanations of the causes of defects. The Institution of Civil Engineers collated studies of structures built with different materials and illustrated the common defects, causes and repairs on these materials (Forde, 2009). Some professional guidance further categorised defects by the nature of their causes (Highways Agency and Technical Project Board, 2007). Other research had paid special attention to road joints and bridge defects (Collins et al., 2017), flexible and rigid pavements (American Association of State Highway and Transportation Officials, 2007, Sec. 2.1.2) and lamp posts (Institution of Lighting Professionals, 2019). These dedicated studies helped enrich knowledge on the causes and preventative treatments for defects at the component level.

Analyses of road assets at the system level

Aside from studying road assets as individual components, an area of research attempted to understand road assets as a system through systemic risk and reliability assessment. These assessment techniques provided structural frameworks to understand the linkages between asset conditions, causes and subsequent actions.

Several techniques aimed to identify suitable repair responses for asset failures. **Risk assessment** was a traditional asset management technique that identified and quantified the impact and probability of potential modes of failure (American Association of State Highway and Transportation Officials, 2022). The **Failure Mode and Effect Analysis (FMEA)** provided an inductive approach to assess the criticality of repair actions by identifying the potential failure modes, their causes and effects, detection methods for such failure modes, and prioritising criticality with the Risk Priority Number (Liu, 2016). **Reliability Centred Maintenance (RCM)** provided techniques to find suitable maintenance solutions by identifying the functions of concerned assets and their failures, modes, effects and consequences in a decision diagram (Regan, 2012). Researchers demonstrated ways to apply these techniques to prioritise repairs for the most deteriorated piece of infrastructure (Macura et al., 2022). The outcome of these analyses enabled road maintenance authorities to implement a combination of proactive and reactive responses to asset failures (American Association of State Highway and Transportation Officials, 2022).

Fault Tree Analysis (FTA) on the other hand provided a deductive approach to diagnosing the root cause of a failure. It commenced with an undesired top event and cascaded to basic events (root causes) and gate events (logic between causes). The FTA had a history of applications in system safety analysis, starting with Boeing in the 1960s and permeating to research on road safety (Yaghoubpour et al., 2016) in recent years. These risk and fault analysis techniques provided inductive and deductive methods in the decision-making for road asset management.

Asset decision trees

The appreciation of road assets as individual components and as a system distil into decision trees for asset maintenance, potentially supported by pavement management systems. Road maintenance authorities linked road assets with conditions and subsequent actions when constructing their maintenance database systems, as illustrated in documents in Table II.

Researchers advanced from coded database entries to mapping defects, causes and repairs of road assets in matrices and graphs. Tee (Tee & Ekpiwhre, 2019) and Orugbo (Orugbo et al., 2015) postulated functions, failure modes and causes of categorized road assets and assigned criticality as part of their RCM analyses. Hadjidemetriou (Hadjidemetriou et al., 2020) categorised pavement distresses and proposed a decision support system. Haas (Haas et al., 2015) prepared decision trees to demonstrate alternative rehabilitation and maintenance solutions on flexible and rigid pavements. The matrices and graphs made attempts to weave relationships between failures and causes of concerned road assets, notably on pavements.

Beyond decision trees on pavements and matrices of off-pavement assets, asset decision trees and recommendation systems were employed in other fields. Similar techniques were also employed in drainage assets, mapping defects, impacts, causes and potential remedies in matrices (Spink et al., 2014). WebMD in medicine provided diagnostic tools that allowed patients to input symptoms they felt and responded with diagnosed diseases and treatment recommendations based on decision trees at the system backend (WebMD LLC, 2022). These applications showed that successful structuring and implementation of decision trees could improve the clarity of thinking steps and coherence of conclusions in decision-making.

The studies of road assets at the component and system level improved the breadth and depth of understanding of road assets. They however only targeted a handful of road assets with limited linkages, typically directed to the most critical cause or mode of failure. A gap in knowledge remains on mapping major types of road assets to defects, causes, repairs and preventative treatments using standardised naming. There also had not been a grouping of defects based on common causes and repairs. This research aimed to provide a methodology to understand the conditions of road assets to address the above-mentioned two gaps.

Table 2: Maintenance guidance linking conditions of road assets other than pavement

Country/ Region	Documentation and authority	Entities to which codes were given	Content coverage
US	AASHTO Bridge Element Inspection Guide Manual (American Association of State Highway and Transportation Officials, 2010) By the American Association of State Highway and Transportation Officials (AASHTO)	Categories of bridge elements (with assets applicable on roads, e.g. railings and joints)	✓ defect types ✓ criteria for condition state scores ✓ general feasible actions (do nothing, repair, replace)
UK	User Manual for the Highways Agency's Routine Maintenance Management System (Highways Agency, 1996) By the Highways Agency	Categories of road assets, defect types and suggested repair	✓ defect types ✓ suggested repair ✓ severity measures
Ontario, Canada	Maintenance Quality Standards and Maintenance Best Practices (Ministry of Transportation Ontario, 2003) By the Ministry of Transportation Ontario, Canada	Categories of road assets	✓ defect types ✓ required operation standards ✓ suggested preventive/corrective maintenance
HK	Road Inspection Manual (Highways Department, 2016) and Catalogue of Road Defects (Highways Department, 2013) By the Highways Department of Hong Kong Special Administrative Region	Categories of road assets and defect types	✓ defect types ✓ possible causes (for some assets) ✓ severity measures ✓ recommended remedies

Table 3: Selected countries and regions for a sanity check

Country/Region	Main governing body	Reviewed states [document]
Australia	Austroads	• New South Wales (Transport for New South Wales, 2013) • Victoria (The Principal Engineer Structures, 2018)
Canada	Transport Canada	• British Columbia (The Ministry of Transportation and Infrastructure British Columbia, 2018) • Ontario (Ministry of Transportation Ontario, 2003, 2018)
US	Federal Highway Administration	• California (Caltrans) (California Department of Transportation, 2014, 2021) • Texas (TxDOT) (Stevenson, 2021; Texas Department of Transportation, 2018)
Hong Kong	Highways Department	Citywide [Publicly available documents on road defects (Highways Department, 2013, 2016) and noise barriers (Highways Department, 2003)]

Methodology

The proposed method aims to map road assets in a network graph with 5 classes of information: assets, defects, repairs, causes and preventative treatments. This method assumes all classes of information are known and without unforeseen force majeure or irreparable defects. The classes of information are assumed to be documented and extractable from some codes of practice.

The selection of road assets

The concerned **road assets** are first defined. The road assets studied in the research are based on an asset tree prepared by Ding (Ding & Brilakis, 2023). The asset tree includes roadside assets (the street furniture) and on-road assets (markings and assets attached to the surface), which road maintenance and this study focus on. The road surface itself has prolonged been studied in separate research, such as Hadjidemetriou (Hadjidemetriou et al., 2020) and the Highways Department of Hong Kong (Highways Department, 2013), and will be excluded from this study. Assets such as mobile objects (e.g. vehicles) and specialist road assets (e.g. retaining walls, bridges, drainage and vegetation) are out of the scope of this study. This study further splits roadside and on-road assets into different types and categories.

Asset types are defined with inspiration from Ding's work. Roadside assets are split by the manner that they are spatially placed on roads. "Freestanding structures" are structures that are placed at fixed points along the road, such as masks and gantries. "Mounted Furniture" includes assets that need to be attached to other structures, such as street signs. Structures that are placed linearly along the trajectory of the road are split into two types in this study, namely "Fences and Barriers" and "Kerb and Pavement". This split reflects the difference in their functions, which lead to different defects and repair methods. These asset types are further subdivided into different categories and assets.

The assets chosen to be mapped in the network graphs are re-categorised from Ding to better reflect the needs from the road maintenance perspective. Assets such as traffic signs have different thresholds that prompt interventions, so they are grouped into "regulatory or warning traffic signs" or "informatory or directional traffic signs". Other assets such as fences and parapets are regrouped by their composition material to better represent their similar defects and causes. Appendix 1 shows the list of investigated assets, asset types and asset categories.

Details of other classes of information

After defining the assets and their grouping, the study proceeds to find other classes of information. The entries for **defects** and **repairs** are found by first consulting relevant documentation in the UK as shown in Table I. Using the luminaires as an example, the author finds the "defects" and "repair" strategies from the Design Manual for Roads and Bridges (DMRB), particularly from clauses in volume TM 501 (National Highways, 2020).

Based on the identified possible defects and repairs, pertinent **causes** and **preventative treatments** are found by referring to research on specific types of road assets conducted by professional institutes. In the case of luminaires, the CIHT published a code of practice on electronic traffic equipment. The code illustrated how common defects of luminaires came about (the "causes") and long-term strategies to deal with the defects (the "preventative treatments"). The entries for different classes of information are listed for processing.

The naming of these entries is then **harmonised and abstracted**. For example, different electrical components may suffer from “malfunctioning” (Class defect) for all electronic failures, necessitating “repair” (Class repair) for all fixes that do not require wholesale “removal and replacement” (Class repair). The naming used for all classes of information is listed in Appendix 2.

The list of defects is subsequently grouped into **diseases** for understanding road defects as a collective problem. The following rules apply to the construction of diseases from individual defects.

1. Similar assets exhibit the same defects
2. Defects similar in nature.
3. Similar combinations of defects and causes
4. Repairs similar in nature
5. Defects to be measured by the same/similar severity

Appendix 3 details the list of diseases and the rationales for the grouping. To illustrate how the rules are applied to group the defects, using “damage and collapse” (Disease #5) as an example, defects in this disease group include “structure failure”, “damaged”, “missing”, etc. The defects are similar in nature (reason 2) that external impact forces physically destroy the assets. This differentiates from slow metallic deteriorations (Disease #6) with more colossal damages. The same defect can appear due to other causes, such as “missing” through theft, which other diseases will deal with.

Following on from their similar nature, these defects also share a similar combination of causes (reason 3) and hence can often be remedied by similar repair strategies (reason 4). The common causes of physical damage include vehicle damage, poor maintenance/construction and frequent contact with traffic (wear and tear (traffic)). The physically damaged assets often need a replacement, a reconstruction, or a repair if they are broken but remain with some remnants.

Connections between the classes and graph plotting

Having formulated the diseases and gathered a list of entries with harmonized naming, the study proceeds to **connect the rational combinations** between the adjacent classes in “Repair – diseases – causes – preventative treatments”. Linkages are built from instructions in inspection manuals or inferred from recommendations in other documents. In the previous example of luminaires, TM 501 of the DMRB provides for a “removal and replacement” (Class repair) of the luminaire when there is an “electric fault” (Class disease).

The contents are further enhanced by carrying out a **sanity check** with standards from overseas jurisdictions. The sanity check allows references to different maintenance jurisdictions, which may provide additional information on specialist assets not covered in the UK, or supplement provisions with more substantial details. Table III summarises the 8 jurisdictions and the reviewed documentation that are available publicly. The **severity** of the diseases is prescribed by the actioning thresholds in these jurisdictions.

The entries and linkages are consolidated in a network graph with the entries in harmonised naming. The graphs are plotted by the Python module Networkx. Each asset/defect/repair/cause/preventative treatment is drawn as a node and causal relationships are drawn as an edge between two nodes. The weights of nodes and edges are set uniformly, but the colours are set according to the frequency of the linked node.

Results and Discussions

This research identified 66 Assets, 48 defects, 28 repairs, 27 causes and 39 treatments. Appendix 1 showed the list of 66 studied assets and their allocations into 6 asset types and 19 asset categories. Appendix 2 recorded the studied defects, repairs, causes and treatments. The 48 defects were grouped into the following 15 diseases with defect grouping and rationale provided in Appendix 3 and the thresholds of severity in Appendix 4. Network graphs are plotted by each asset category.

- Vandalised
- Fading sign
- Poor establishment
- Electrical faults
- Damage and collapse
- Slow deterioration (Metallic)
- Worsen appearance
- Mechanical faults
- Hinderance
- Misalignment
- Forbidden access
- Diseases of natural resources
- Slow deterioration (masonry or concrete)
- Ground failures
- Drainage-related failures

The graphs could be interpreted in two ways illustrated in Figure 1 and Figure 2. The first way attempted to deduce causes and explore relevant preventative treatment from known defects, while the second way inferred possible diseases and corrective repair methods from known causes. Both ways first required the asset category in concern to be identified.

From the first way of interpretation, surveys by the road maintenance authority revealed defects in road assets. With a known defect, the graph reader could find the corresponding disease from the second column. The reader could then know the possible causes and useful preventative treatments by following the linkages from the second to the third column and the matrix table.

The second way of interpretation typically required an a priori understanding of a geographical area and potential causes of common problems in the area. With the causes in the third column in mind, the graph reader can find the applicable disease and their corresponding corrective repairs in the first two columns. This allowed repair options to be enumerated for maintenance planning.

The network graphs of conditions of road assets contribute first to bringing segregated road asset failures into a comprehensive network of conditions. The different nomenclature used between British-influenced (UK, Australia, Hong Kong) and American-influenced (the US and Canada) jurisdictions can be harmonised. The grouping of diseases benefits high-level solution finding by focusing on the strategy of asset management without being distracted by the particularities of the exact repair method.

The networks further benefit road maintenance at the system level by providing a starting point to automate maintenance tasks and facilitate risk analyses in maintenance decision-making. The network lays the ground rules of what defects may potentially happen on a detected object and their possible causes and treatments. The defects and causes in this research can serve as failure modes and causes in FTA and FMEA. Information on repair and preventative treatment in this research provides options for FMEA and RCM. The additional task required to harness the full benefits of the system-level network is the need for more details. Planners would need to gather statistics to quantify the probabilities of failure, the cost of maintenance and the implications of time to evaluate options for road maintenance.

Conclusions

Despite decades of experience and major expenditure on road infrastructure, defects of road assets were often disconnected from their causations and recommended repair actions. This led to treatments of symptoms but not their underlying disease. This research merged segregated road asset failures into a comprehensive network by referring to a hierarchy of documentation on road maintenance. The network concluded 15 diseases of defects out of 19 categories of assets into 28 repairs, 27 causes and 39 preventative treatments. The types of failures and actions identified in this paper were consistent with the defects described in previous literature.

The networks of conditions of road assets provided the framework that facilitates automation and risk analyses in asset management. The networks lay the ground rules for automating road maintenance and enumerate options for risk analyses. This benefits maintenance option selections at a strategic level for asset management planners and the automation of decision-making. Future research work may include enriching the depth of the network with practice, quantifying relationships and adding the implication of time. This proposed analysis method can be applied to many other practical projects, including buildings, railways and bridges.

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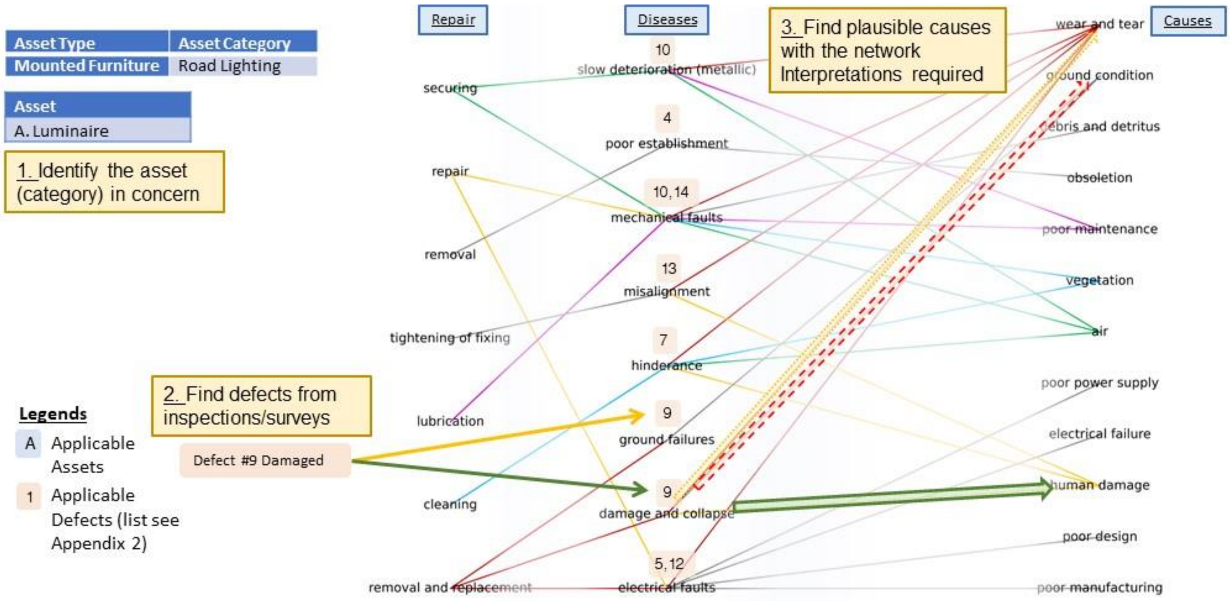
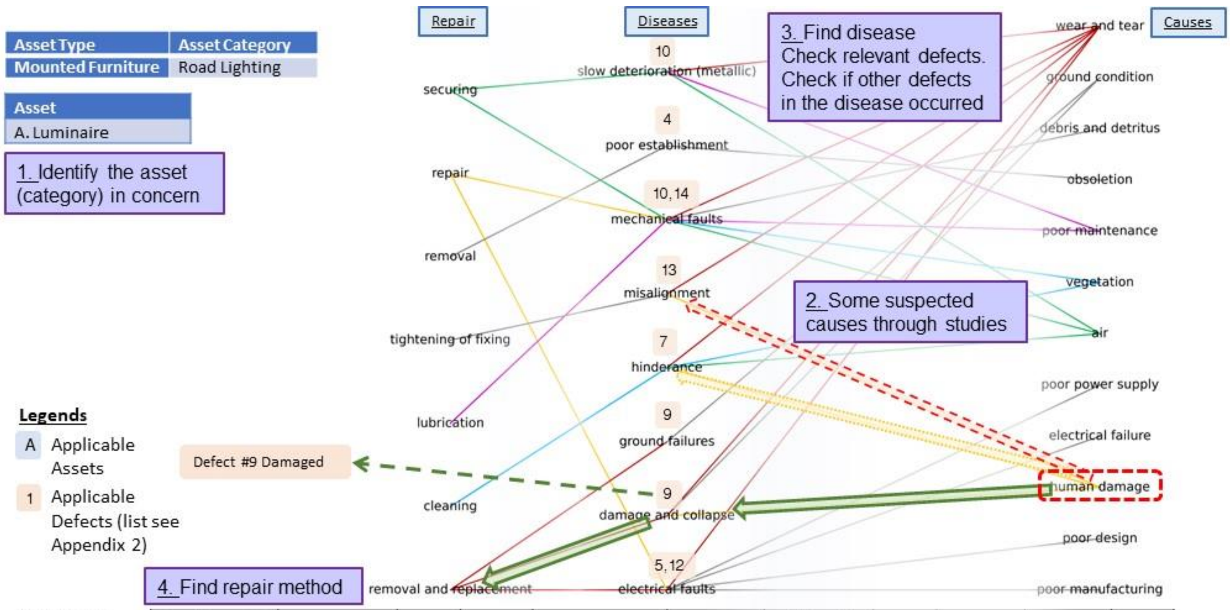


Applicable Preventative Treatments

Cause \ Preventative Treatment	regular inspection and maintenance	better reporting	regular lubrication	regular checks on security implements	regular testing and inspection	maintain with manufacturer's guidelines	regular cleaning	preventative maintenance	ensure spare components	better design
wear and tear	O	O			O	O		O	O	
ground condition	O									
debris and detritus	O						O	O		
obsoletion						O				O
poor maintenance	O		O							
vegetation	O							O		
air	O						O			
poor power supply	O	O			O	O		O		
electrical failure	O	O			O	O		O		
human damage	O			O		O				O
poor design	O							O		O
poor manufacturing	O	O			O	O		O		

Figure 1: Interpretation of Network (Method 1)



Applicable Preventative Treatments

Cause \ Preventative Treatment	regular inspection and maintenance	better reporting	regular lubrication	regular checks on security implements	regular testing and inspection	maintain with manufacturer's guidelines	regular cleaning	preventative maintenance	ensure spare components	better design
wear and tear	O	O			O	O		O	O	
ground condition	O									
debris and detritus	O						O	O		
obsoletion						O				O
poor maintenance	O		O							
vegetation	O							O		
air	O						O			
poor power supply	O	O			O	O		O		
electrical failure	O	O			O	O		O		
human damage	O			O		O				O
poor design	O							O		O
poor manufacturing	O	O			O	O		O		

Figure 2: Interpretation of Network (Method 2)

Appendix 1 List of Investigated Assets, Asset Types and Asset Categories

Asset Type	Asset Category	Asset
Mounted Furniture	Traffic Signs	Informatory or directional traffic signs
		Regulatory or warning traffic signs
	Road Lighting	Luminaire
	Control and Communications	CCTV
		Road safety cameras
		Traffic Signal
		Electronic Sign
	Mounted Enriching Objects	Utility Cable
		Utility Poles
		Cell Tower Antenna
Fences and Barriers	Fences and Sound Barriers	Brick Walls
		Noise barrier
		Metal/concrete fence
		Wooden fence
		Pedestrial Guardrail
		Hedges
	Road Restraint Systems	Masonry parapets
		Concrete parapets
		Metal parapets
		Bollard
	Gates and Stiles	Metal gate
		Wooden gate
Kerb and Pavement	Traffic Channeling	Traffic islands
		Chicane
	Kerb	Block kerb
		Piped Drainage System
		Piped Grip
	Sidewalk/ Road Verge	Asphalt/concrete footways
		Pavers footways
		Grass
Freestanding Furniture	Mounts	Cable
		Masts
		Sign and signal gantries
	Essential Objects	Feeder Pillars
		Emergency Roadside Telephone
	Enriching Objects	Bus Shelter
		Postbox
		Bench
		Cycle Stand
		A-board

Asset Type	**Asset Category**	**Asset**
		Parking Meter
		Planters
		Phone box
		Bins
		Fire Hydrants
		Trees
		Charging Points
Road Markings	Longitudinal Lines	Longitudinal marking
	Transverse Lines	Transverse marking
	Nonlinear Markings	Nonlinear marking
Road Surface Structures	Channels	Grips
		Ditches
	Traffic Calming	Rubber Speed Cushion
		Concrete Speed Cushion
		Block Speed Cushion
		Thermoplastic Road Hump
		Pre-formed Road Hump
	Other	Covers
		Gully
		Cattle Grid
		Studs
		Vehicle carriageway loop
		Asphaltic plug joint
		Reinforced elastomeric joint
		Nosing joint
		Modular joint

Appendix 2 List of Defects, Repairs, Causes and Treatments

Defect

1. graffiti and flyposting
2. material fault
3. marking degradation
4. incorrect placement
5. illumination failure
6. structural failure
7. obscuration
8. missing component
9. damaged
10. loosen component
11. corrosion
12. malfunctioning
13. misaligned
14. mechanical failure
15. disconnection from network
16. access issues
17. dirtiness
18. loosen fixing
19. encroachment of vegetation
20. cracking
21. discolouration
22. brick failure
23. surface defects
24. external agent defects
25. deformation
26. missing
27. difference in level
28. obstruction
29. rotten
30. animal infestation
31. diseased
32. weed growth
33. overgrown vegetation
34. foundation failure
35. ground failure
36. encroachment of barbed wire
37. joint opening
38. pothole
39. blockage
40. rocking
41. detritus
42. flooding and standing water
43. scour
44. leakage
45. litter and rubbish
46. power failure
47. illegality
48. sealing failure

Cause

- air
- animals
- bi-metallic corrosion
- chemical reaction
- compromised systems
- debris and detritus
- electrical failure
- fire and explosion
- ground condition
- human damage
- illumination
- material degradation
- moisture
- movement of surroundings
- obsoletion
- poor construction
- poor design
- poor installation
- poor maintenance
- poor manufacturing
- poor operation
- poor power supply
- poor reinstatement
- vegetation
- vehicle damage
- wear and tear
- weather

Repair

- additional component
- adjust level
- chemical treatment
- cleaning
- concealment
- diversion
- enforcement
- foundation improvement
- gear maintenance
- lubrication
- modification
- provision
- reconsider need
- reconstruction
- relocation
- removal
- removal and replacement
- removal of vegetation
- repainting
- repair
- replacement
- restore
- reuse
- securing
- tightening of fixing
- tying
- unblocking
- user constraints

Treatment

- better anchorage
- better choice of species
- better construction
- better design
- better drainage
- better installation
- better maintenance
- better material
- better materials
- better operation
- better preparation
- better protection
- better reporting
- better security control
- careful consideration
- competence
- compliance with guidance
- consultation
- design for the minimum
- design in accordance with guidance
- effective enforcement
- elimination
- ensure spare components
- good visibility
- higher standard product
- isolation
- maintain with manufacturer's guidelines
- more intensive maintenance
- preventative maintenance
- preventative technologies
- redundancy
- regular checks on security implements
- regular cleaning
- regular inspection and maintenance
- regular lubrication
- regular testing and inspection
- substitution
- timing of maintenance
- whole life cycle management

Appendix 3: Disease Grouping and Rationale

ID	Group name	Common grouped defects	Reason	Remarks
1	Vandalised	Graffiti and flyposting Missing component Loosen component Missing Discolouration Damaged Deformation	3, 4	(3) Common: vandalism (4) Removal and replacement common. Provide if stolen (missing)
2	Fading sign	Marking degradation Material fault		Material fault for non-signalling assets
3	Poor establishment	Incorrect placement Illegality Litter and rubbish Loosen component Discolouration Cracking Sealing failure	1, 3, 4	(1) subject to asset type (3) common: poor construction/installation (4) common: repair dominant. Replace if broken or secure if loosen
4	Electrical faults	Illumination failure Malfunctioning Disconnection from network Power failure	1, 2, 3, 4	(1) electrical appliances (2) Some form of electrical/electronic/ information failure (3) common: wear and tear, electrical failure (4) repair or restore
5	Damage and collapse	Structural failure Damaged Deformation Cracking Missing Foundation Failure Missing component Joint opening Loosen fixing	2, 3, 4	(1) Usually refers to erected structures or linear structures. Subject to asset type (2) all point to physical damages more catastrophic than material-led deterioration (3) common: vehicle damage, wear and tear (traffic), poor maintenance/construction (4) common: replacement and reconstruction. Repair if broken, replace if missing
6	Slow deterioration (Metallic)	Corrosion Cracking Loosen fixing Loosen component Material fault Deformation Structural failure Damaged	1, 2, 3, 4	(1) Roadside appliances/structures with metal parts (2) symptoms of time related deterioration and not abrupt damage (c.f. #5) (3) common: poor maintenance, wear and tear, material degradation, chemical reaction, air (4) repair, replacement dominant. Tightening if loosen
7	Worsen appearance	Discolouration Dirtiness Marking degradation	2, 3, 4	(2) loss of appearance (3) common: air(dirt), wear and tear (traffic), poor design. Additional causes for discolouration (4) repaint, cleaning dominant (optional: replace if discoloured) Note: not combined with obscuration (#9) because the function of the asset is not impaired here (different nature of defect, failed rule 2)
8	Mechanical faults	Loosen component Malfunctioning Mechanical failure	2, 3, 4	(2) Parts become faulty because it is stuck mechanically, or signal fails to pass electronically (3) common: poor maintenance, human damage. Additional causes for malfunctioning (4) common: lubrication, repair, replacement

ID	Group name	Common grouped defects	Reason	Remarks
9	Hinderance	Obscuration Obstruction Overgrown vegetation Litter and rubbish Encroachment of vegetation Blockage Detritus Weed growth	1, 2, 3, 4	(1) subject to asset type (2) obstructing the right of way, traffic/water flow or mechanical open/close function (3) common: poor maintenance, wear and tear (optional: vegetation, human damage) (4) removal, unblock dominant
10	Misalignment	Misaligned Difference in level Rocking Sealing failure	1, 2, 3	(1) movable assets (pavers, concrete block, gully cover etc..) or assets assembled from building blocks (parapets, walls, pipes etc..) (2) displacement from its intended position (3) common: poor design, poor installation/ construction (optional: ground condition)
11	Forbidden access	Access issues Encroachment of barbed wire	1, 2, 3	(1) gates (2) problems that impede movement across the assets (3) poor maintenance
12	Diseases of natural resources	Weed growth Diseased Animal infestation Rotten Encroachment of vegetation Overgrown vegetation	1, 2, 3, 4	(1) plants, wooden assets or influence of plants to assets (2) "illnesses" from nature (3) common: vegetation and poor maintenance (optional: animals, weather) (4) remove vegetation and repair the asset
13	Slow deterioration (masonry or concrete)	Brick failure Surface defects External agent defects Cracking Structural failure Damaged Loosen component Loosen fixing Joint opening Material fault Missing component Pothole	1, 2, 3, 4	(1) Masonry or concrete assets (2) imperfection taken place on a material (3) common: wear and tear, poor maintenance (optional: poor manufacturing, poor construction/reinstatement, material degradation, vegetation, ground condition, air, weather, moisture, chemical reaction) (4) repair or reconstruction dominant
14	Ground failures	Ground failure Foundation failure Structural failure	2, 3, 4	(1) Usually on drainage or foundations (2) geotechnically related. The ground being weak or surrounding movements disturbing the ground and causing damage to the drain (3) common: ground condition (4) reconstruction or replacement dominant
15	Drainage related failures	Malfunctioning Scour Flooding and standing water Deformation Blockage Leakage	1, 2, 3, 4	(1) Drainage related or spills from poor drainage to footways (2) Defects caused by water flow or as a result of (poor) water flow (3) common: weather, debris, vegetation, poor maintenance (optional: human damage) (4) repair dominant. Optional reconstruction or replacement. Unblocking if problems of blockage

Note: Reasons refer to the section of **Methodology**

Appendix 4 Severity Grouping

Asset Type: Mounted Furniture

Disease	Defect	Metric	Severity Level 1	Severity Level 2	Severity Level 3	Severity Level 4	Remarks
Fading sign	Material fault	Minimum clear visibility distance	<u>Regulatory or warning signs</u> Stop: 20mph: 15m; 70mph: 120m-250m (UK, AUS) Speed repeater: 20mph: 20m; 70mph: 75m (UK) Speed changing: 20mph: 30m; 75mph: 200m (US, AUS, UK) Speed and lane changing: 20mph: 68m; 75mph: 409m (US)		<u>Information signs</u> General directions: 20-70mph – 35m-180m (UK) Advanced direction or route confirmation: 20-70mph – 45m-180m (UK)		
Fading sign	Marking degradation	Minimum retroreflectivity	Black on green (G), yellow (Y) or orange (O): G/Y/O > 75 White (W) on red (R): W>35, R>7, W/R > 3 Black and White (W): W>35-50		White (W) on Green (G): Overhead: W>250, G>25 Post mounted: W>120, G>15		Units in cd/lux/m^2 Minimum clear visibility distance also applicable (US, CAN)
Hinderance	Obscuration	Minimum clear visibility distance	20mph: 45m-70m (US, UK) 70mph: 105m-245m (UK, US, CAN)				
		Breaking distance	Corrective: 2.5-5 seconds		Amenity: 5-8 seconds		AUS
Slow deterioration (metallic)	Corrosion	Loss of section	<5%	5-10%	10-20%	>20%	UK, CAN
	Cracking	Area	0	<10%	10-50%	>50%	UK
Worsen appearance	Discolouration	Area	0	<10%	10-50%	>50%	UK

Asset Type: Fences and Barriers

Disease	Defect	Metric	Severity Level 1	Severity Level 2	Severity Level 3	Severity Level 4	Remarks
Damage and collapse	Damaged	Loss of section	<5%	5-10%	10-20%	>20% or collapsed	UK, CAN
	Damaged (Concrete)	Displacement	0	0	<20mm	>20mm	AUS
	Damaged (Wood)	Wood cracks	0	<10% member depth	<50% low flexure and <25% high flexure	>50% low flexure and >25% high flexure	UK, US
		Area of deterioration	>10%				CAN
	Deformation		Metal parapet: 200mm protrusion (AUS); 75mm sagging or buckling (CAN)				
Slow deterioration (masonry or concrete)	Cracking (masonry)	Width	<0.1mm	0.1-0.3mm	0.3-1mm	1-3mm	UK, CAN, US
		Crack spacing	N/A	0.33-1m	<0.33m	Structural review	
	Surface defects (masonry)	Loss of section	<50mm depth	50-100mm depth	100-150mm depth	>150mm depth	CAN
		Efflorescence	None	Surface white	Build up with rust stain	Structural review	US
	Brick failure (masonry)	Loss of mortar	<20mm depth	20-50mm depth or <10% joints	A few stones lost or >10% joints	Stability endangered	CAN, US
	Cracking (concrete)	Width (UK)	<0.3mm at low flexure	1mm crack at high flexure	>2mm crack or shear crack	Failure	UK
		Width (US)	<1.6mm	1.6-3.2mm	>3.2mm	Structural review	US
		Crack spacing	>1m	0.33-1m	<0.33m	Structural review	US
	Surface defects (concrete)	Loss of surface mortar	<5mm depth	6-10mm depth	11-20mm depth	>20mm depth	CAN
		Spalling length	<150mm	150-300mm	300-600mm	>600mm	CAN, US
		Spalling depth	<25mm	25-50mm	50-100mm	>100mm or rebar exposed	CAN, US
	Material fault	Loss of section	<25mm depth	25-50mm depth	50-100mm depth	>100mm depth	CAN
		Delaminated area	<150mm length	150-300mm length	300-600mm length	>600mm length	CAN
Slow deterioration (metallic)	Corrosion	Loss of section thickness	0	<5%	5-20%	>20% or structural review needed	UK, AUS, CAN, US
	Loosen fixing	Amount loose	None	<5%	5-10%	>10%	CAN, US
Worsen appearance	Discolouration	Surface rusted	<1%	1-3%	3-10%	>10%	AUS, CAN
Diseases of natural resources	Rotten, Animal infestation	Loss of section	<5% or on surface	5-10%	10-20%	>20% or collapsed	UK, CAN, US

Disease	Defect	Metric	Severity Level 1	Severity Level 2	Severity Level 3	Severity Level 4	Remarks
	Encroachment of vegetation		Within 1m of authority boundary fence Within 3m of fauna fence				AUS
Mechanical faults	Mechanical failure	Guardrail post spacing	<2m	2-2.5m	2.5-4m	>4m	AUS
			Sediment <150mm below the grid				AUS
Misalignment	Misaligned		Height and lateral misalignment: 75-100mm (CAN, AUS); 300mm (US)				

Asset Type: Freestanding Furniture

Disease	Defect	Metric	Severity Level 1	Severity Level 2	Severity Level 3	Severity Level 4	Remarks
Damage and collapse	Structural failure		Max charge of 818kg car striking at 710mm above the top of foundation to break the pole				US
Hinderance	Obstruction, overgrown vegetation	Maximum height (Tree)	200mm in pedestrian zones, 300mm in urban areas, 500mm in rural areas (AUS) 2m at interchange, 3m at Road 1-3, 4m at Road 4-6 (CAN)				
	Obstruction	Lateral Clearance	0-3m from shoulder (CAN) 0.6m from guardrail, 5.2m from shoulder (US)				
Slow deterioration (metallic)	Corrosion	Loss of section	<5% area	5-10% area	10-20% area	>20% area	AUS, CAN
			0	<10% area	10-50% area	>50% area	UK
	Cracking	Area	0	<10% area	10-50% area	>50% area	UK
Worsen appearance	Discolouration	Rusted surface	<1% area	1-3% area	3-10% area	>10% area	AUS, CAN
			0	<10% area	10-50% area	>50% area	UK

Asset Type: Kerb and Pavement

Disease	Defect	Metric	Severity Level 1	Severity Level 2	Severity Level 3	Severity Level 4	Remarks
Damage and collapse	Cracking		20-30mm width; 200-300mm length				UK, CAN, US
	Cracking (concrete slabs)	Crack depth	<13mm	13-51mm	51-102mm	>102mm	US
		Crack density	None	<20 per 30m	>20 per 30m		
	Cracking (Drainage)	Crack depth	Surface	1-1.5x pipe thickness	>1.5x pipe thickness	Multiple cracks or split	UK, US
Diseases of natural resources	Weed growth		25mm protrusion; 35% areas in areas mulched with wood chips				CAN
	Overgrown vegetation		500mm height within 2m of outside edge				CAN
Drainage related failures	Scour		None	Arrested	Exist	Structural review	US
			250mm depth; 100mm structure undermined				AUS
	Flooding and standing water		5-10mm depth; restricted footway to <0.9m walkable width				UK, AUS
Hinderance	Blockage (Drainage)	Sediment depth	0	<25% pipe diameter	25-75% pipe diameter	>75% pipe diameter	UK
		Size of foreign object intrusion	<5% pipe diameter	5-25% pipe diameter	20-75% pipe diameter	>75% pipe diameter	UK
		Flow capacity	50% flow capacity				AUS, CAN, US
	Detritus	Deposit	<5% CSA	5-20% CSA	20-75% CSA	>75% CSA	UK. CSA – cross sectional area
	Encroachment of vegetation	Occupancy in pipe	<5% CSA	<20% CSA	20-50% CSA	>50% CSA	UK. CSA – cross sectional area
	Obstruction	Size of object	100mm diameter or 0.015m^3 volume				CAN
		Mount objects	Mounted on wall or side: 100mm into the sidewalk Mounted on a post: 300mm into the sidewalk Height: no lower than 2.00m or no higher than 0.70m				US
		Clear width of footway	>1.2m	0.9-1.2m	<0.9m		US
Misalignment	Rocking	Vertical misalignment	10mm (AUS); 20-25mm (UK)				
	Difference in level, misaligned	Vertical misalignment	13-20mm (UK, AUS, HK, CAN, US) 40mm abrupt discontinuity (AUS); 100mm slab settlement (CAN)				
		Slopes	Transverse to street/property ≥1:20; longitudinal ≥1:12				US
Slow deterioration (masonry or concrete)	Pothole	Depth	20mm (UK, HK, CAN, US); 50mm (AUS)				
		Diameter	100mm (UK)				
	Surface defects	Spalling depth	13-38mm (UK, US)				
		Spalling area	3m^2 (CAN); 50% of a single panel or 50mm width broken				

Disease	Defect	Metric	Severity Level 1	Severity Level 2	Severity Level 3	Severity Level 4	Remarks
Slow deterioration (metallic)	Deformation (pipes)	Pipe size	Plastic: <10% Rigid: 0	Plastic: 10-20% Rigid: <5%	Plastic: 20-33% Rigid: 5-10%	Plastic: >33% Rigid: >10%	UK
		Lining damage	>1m^2 concrete or lining broken				AUS

Asset Type: Road Surface Structures

Disease	Defect	Metric	Severity Level 1	Severity Level 2	Severity Level 3	Severity Level 4	Remarks
Damage and collapse	Cracking	Crack width	20mm wide (gully cover)				HK
	Damaged	Length	Continuous >2m (gully cover)				AUS
Poor establishment	Loosen component	Relative movement	10mm				HK
Hinderance	Blockage	Cover capacity	Hinderance of >25% capacity				AUS
	Blockage (gully)	CSA blocked	<5%	5-20%	20-75%		UK
Misalignment	Difference in level	Upstand	6mm at traffic calming (UK) 15-25mm from abutting carriageway, footway or cycle track (UK, AUS, HK)				
Vandalised	Missing component Damaged	Studs: Casting or lenses missing	Overall 25%; Tangent: 3 or more consecutive, Curve: 2 or more consecutive (CAN)				

Asset Type: Road Markings

Disease	Defect	Metric	Severity Level 1	Severity Level 2	Severity Level 3	Severity Level 4	Remarks
Fading sign	Material fault	Wear	No obvious wear or very little	Marginal	Bare spots	Barely visible or residue	UK
		Loss of profile line texture	0-20m	20-30m	30-50m	>50m	Counted if over 80% of section. AUS
		Build-up of line thickness	<6m	≤6m	>6m		AUS
		Skid resistance accepted range	20% SRT <45, or 0% SRT<36				HK
			Critical area SRT <55; non-critical SRT<45				UK
		Visibility distance	25-70mph – 140m-360m (US) 100% visible at the season-end of installation; 70% of markings visible at the start of next season (CAN)				

<table>
<tr><th>Disease</th><th>Defect</th><th>Metric</th><th>Severity Level 1</th><th>Severity Level 2</th><th>Severity Level 3</th><th>Severity Level 4</th><th>Remarks</th></tr>
<tr><td rowspan="6"></td><td rowspan="6">Marking degradation</td><td rowspan="4">Retroreflectivity</td><td colspan="4">By criticality of area:
<100 in lit; <150 in unlit areas for critical areas
<80 in lit;<120 in unlit areas for others
<35 in condition of wetness</td><td>Units in mcd/m2/lux
UK</td></tr>
<tr><td colspan="4">By colour of marking:
white: >100; yellow: >80; temp: >150 (HK)
white: >150; yellow: >75 (CAN)</td><td>Units in mcd/m2/lux</td></tr>
<tr><td colspan="4">By speed limits:<table>
<tr><th></th><th><30mph</th><th>35-50mph</th><th>>55mph</th></tr>
<tr><td>Two-lane road with centreline markings only</td><td>N/A</td><td>100</td><td>250</td></tr>
<tr><td>Other roads</td><td>N/A</td><td>50</td><td>100</td></tr>
</table></td><td>US</td></tr>
<tr><td colspan="4">By road conditions:<table>
<tr><th>Condition</th><th>Category 1</th><th>Category 2</th><th>Category 3</th><th>Category 4</th><th>Category 5</th></tr>
<tr><td>Dry</td><td>350-250</td><td>250-150</td><td>150-100</td><td><100</td><td><100</td></tr>
<tr><td>Wet</td><td>>100</td><td>>70</td><td>≥70</td><td><70</td><td><70</td></tr>
</table>Proportion/distance of roads missing with range<table>
<tr><th colspan="2">Condition</th><th>Category 1</th><th>Category 2</th><th>Category 3</th><th>Category 4</th><th>Category 5</th></tr>
<tr><td colspan="2">In any 300m (urban) or 3km (rural) section</td><td>0-5%</td><td>5-10%</td><td>10-20%</td><td>20-30%</td><td>30-40%</td></tr>
<tr><td rowspan="2">Straights</td><td>Urban</td><td>0</td><td>0-5m</td><td>5-10m</td><td>10-30m</td><td>30-50m</td></tr>
<tr><td>Rural</td><td>0-50m</td><td>50-100m</td><td>100-200m</td><td>200-400m</td><td>400-600m</td></tr>
<tr><td rowspan="2">Curves</td><td>Urban</td><td>0</td><td>0</td><td>0-5m</td><td>5-10m</td><td>10-30m</td></tr>
<tr><td>Rural</td><td>0</td><td>0-50m</td><td>50-100m</td><td>100-200m</td><td>200-400m</td></tr>
</table></td><td>AUS</td></tr>
<tr><td rowspan="2">Luminance</td><td colspan="4">Factor: white <0.30/yellow <0.20</td><td>UK</td></tr>
<tr><td colspan="4">Coefficient: White: Qd>100 on asphalt, Qd>130 on concrete; Yellow: Qd>80</td><td>HK</td></tr>
</table>