INTEGRATED CARBON EMISSIONS CONTROL IN DECISION-MAKING

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ABSTRACT

To keep Auckland moving, Auckland Transport (AT) is proudly providing sustainable management of transport services to connect people and communities. In fast-growing urbanised areas, it has been widely recognised that by planning for long-term goals, authorities can make proactive choices that lay the groundwork for future development. The need to have fit for purpose infrastructure to support the transport network are also vital to meet future goals. While resilience against risks such as climate and environmental changes are considered during designing and building new infrastructure, extending the life of existing infrastructures to cope with those risks are also needed to operate a safe transport network.

Risk management is at the heart of AT's decision making in asset management of its transport structures. It is believed addressing the risks proactively will create safe transport environments and save guard investments. As such, a low carbon economy pushes us to face the carbon emissions from asset management of transport structures seriously.

This paper discusses how to link asset management to the decarbonising goal from the asset management practice. A quantitative carbon emissions framework is proposed to calculate the carbon emissions of the transport structures. It is proposed to capture the life cycle stages of a transport structure to have a full picture in decision-making, including the structure of the new installation, operation/maintenance, and demolition. The guidance documents have been investigated and the carbon emission factors should come from those documents, which was developed to suit the local environment and be updated periodically. This paper also provides an illustrative example to demonstrate the application of this framework in decision making.

The risk management of transport structures is subjected to the constraints like budget, urgency and availability of products and technology. Hence, carbon emissions are one of many factors affecting decision making. With the increased awareness of carbon emission control from society, carbon emissions should be considered part of the multi-criteria decision-making approach at road authorities.

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INTRODUCTION

New Zealand passed a bill on November 7, 2019, requiring the country to be net-zero for all greenhouse gases by 2050 (except for biogenic methane, with plans to reduce that by 24%–47% below 2017 levels by 2050).

This can be an ambitious target unless we have a collective effort from society. At Auckland Transport (AT), we are investigating what this goal means to us and efforts are required to align ourselves as the custodians of the $21 billion value of transport assets.

New Zealand is one of the countries that signed off the Kyoto Protocol in 1997 (United Nations, 1997) to reduce the greenhouse gases (GHG). From which, the six greenhouse gases listed in Annex A: carbon dioxide (CO_2), Methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF_6). While Carbon dioxide (CO_2) is recognised as the most important anthropogenic GHG (IPCC, 2013).

According to the Ministry for the Environment, the carbon dioxide emissions from manufacturing industries and construction were 17.9 percent of all carbon dioxide emissions in 2018. This is the place where a sustainable asset management approach can influence reducing greenhouse gases emissions.

To control carbon emissions, we must understand how to measure it from an asset lifecycle, including structural assets. The scope of the whole-of-life embedded carbon framework increases over time and new buildings in the public sector need to meet Whole Life embedded carbon caps at a certain level (MBIE, 2020). It is also noted from the framework that “When caps on embedded carbon are introduced, Building Consent Authorities will need to have the confidence that the data provided is sufficiently robust in demonstrating the whole-of-life embedded carbon is below the cap, in order to award the consent.”

Hence, it is time for us to investigate how to measure the carbon emissions quantitatively from the asset lifecycle, which is described as Planning, Acquisition, Operation and Maintenance, Disposal (AssetWorks, 2017).

To facilitate the embedded carbon emissions analysis, the structural lifecycle is further consolidated into three stages from this paper as New installation, Operation and maintenance and Disposal. The quantitative calculation of the carbon emissions and a framework in guiding our future asset management practices are discussed from the following sections.

CARBON FOOTPRINT AND EMBEDDED CARBON EMISSIONS

It has been well accepted that there are two measures of carbon emissions, carbon footprint and embedded carbon emissions. A carbon footprint is the total greenhouse gas (GHG) emissions caused directly and indirectly by an individual, organisation, event or product, and is expressed as a carbon dioxide equivalent (CO_2-e) (CARBON TRUST, 2018).

Carbon dioxide equivalent (CO_2-e) is the unit of measurement which allows different greenhouse gases to be compared on a like for like basis relative to one unit of CO_2. CO_2-e emissions are calculated by multiplying the emissions of each of the six greenhouse gases by its Global Warming Potential (GWP).

Embedded carbon emissions are the subset of a carbon footprint and can be treated as the carbon footprint of materials. As per the definition from MBIE NZ, Embedded carbon emissions are caused by CO_2 and other greenhouse gases from non-renewable energy sources or otherwise being released into the atmosphere due to activities associated with a particular material or product

(MBIE, 2020).

Transport structures are a key asset in support of transport. Embedded carbon emissions predominantly measure its whole of life carbon footprint. That is also the difference with buildings, where operational carbon is quite significant as well. An indictive illustration of embedded carbon emissions over a transport structure's lifecycle is shown in Figure 1.

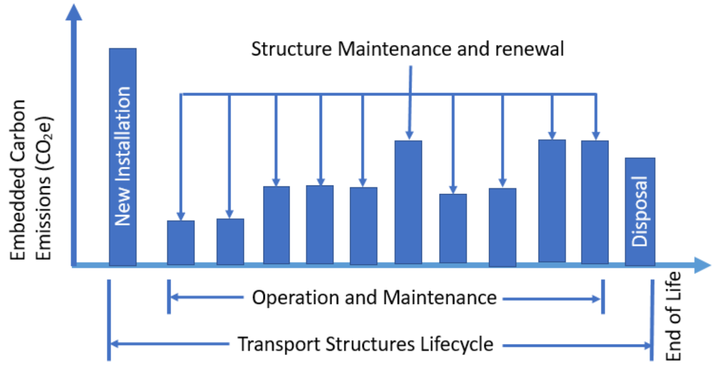

Figure 1. Embedded carbon emissions over the lifecycle of a transport structure

LINKING ASSET MANAGEMENT WITH CARBON NEUTRAL GOAL

As the custodian of transportation assets, we create quality design outcomes for the sustainable management of transport services, connecting people and communities. To provide our contribution to the carbon-neutral goal, a work flow is suggested in Figure 2 below.

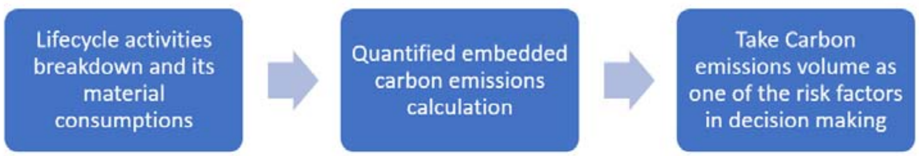

Figure 2. Integrated risk management framework

Lifecycle material consumption

As we discussed in the previous section, the lifecycle of transport structure could be described as a new installation, operation/ maintenance and disposal. All those stages will generate carbon emissions. By taking a bridge's lifecycle as an example, as shown in Figure 3, in-between its initial installation and final demolition, there are multiple maintenance and/or renewals driven by asset conditions and the outcomes from risk assessments.

The embedded carbon emissions could be calculated quantitatively and measured using carbon dioxide equivalent (CO_2e). At the time when the road authority faces a decision at a particular stage, the embedded carbon emissions can then be weighted against other factors.

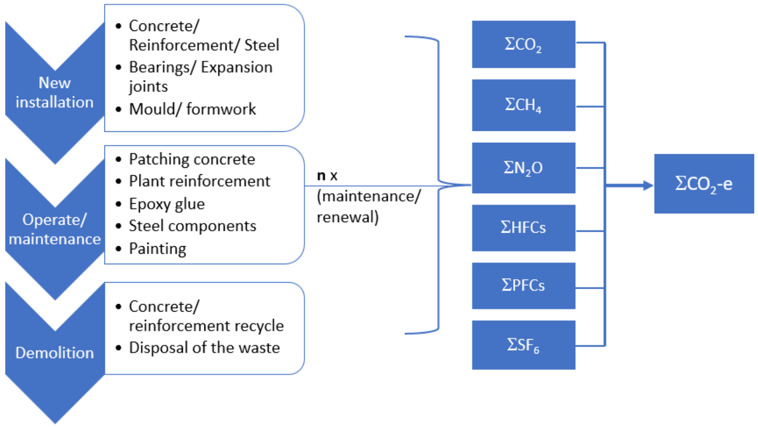

Figure 3. An illustrative lifecycle breakdown of a bridge

Embedded carbon emissions calculation

The calculation of carbon dioxide equivalent is a specialised topic, while its meaning is straight-forward. It provides a measure to describe the various GHG in a common unit. CO_2-e converts any type of GHG to the amount of CO_2, which would have the equivalent global warming effect.

The analysis and rational elaboration can be found from the Intergovernmental Panel on Climate Change (IPCC) report (Myhre, et al., 2013).

As for transport structures, the lifecycle embedded carbon emissions can be expressed as,

$$Ce = \sum_{i=1}^{n} Cei = \sum_{i=1}^{n} \sum_{j=1}^{6} W_{ij} \cdot GWP_j \qquad (1)$$

Where,

Ce, the carbon dioxide equivalent, (kg_CO_2)
i, the i^{th} lifecycle stage
Cei, the carbon dioxide equivalent at the lifecycle stage i
j, one of the six GHG
W_{ij}, the weight of GHG j at the lifecycle stage i, (kg)
GWP_j, Global Warming Potential of GHG j, $(\frac{kg\_CO_2}{kg})$

GWP is periodically updated from the IPCC report (Myhre, et al., 2013).

W_{ij} is the carbon content of materials used in the stage i. Its calculation refers to IPCC Guidelines for National Greenhouse Gas Inventories (Calvo Buendia, et al., 2019).

Carbon emissions in decision making

Knowing the structurally embedded carbon emissions quantitatively, the decisions along the lifecycle of the structures can take the carbon emissions reduction as one of the factors.

If we take reducing the carbon emissions as the single goal, the decision making could be expressed as,

$$Ce_{preferred\ option} = Min\ \{Ce_{opt\_1}, Ce_{opt\_2}, \dots, Ce_{opt\_n}\} \qquad (2)$$

While the decision-making is also affected by multiple boundary conditions, by taking the transport structure as an example, this will be affected but not limited to the budget, the functionality of the structure, the safety factors and the aesthetic demands.

After carrying out the carbon emissions assessment following this paper's framework, the carbon emissions can be a new factor among other factors in the decisions-making process.

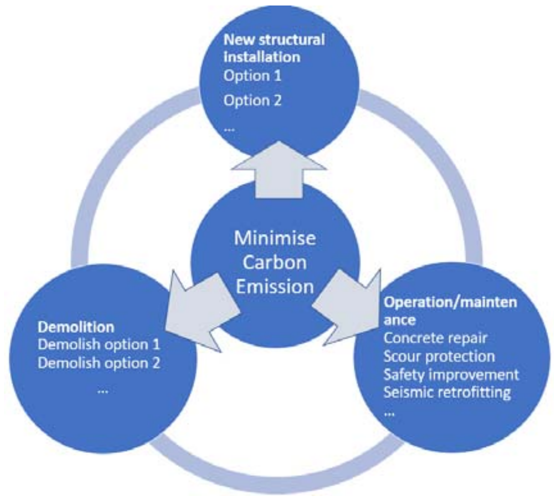

Figure 4. Carbon emissions in decision making of lifecycle asset management

AN ILLUSTRATIVE EXAMPLE

General description

To illustrate the framework proposed, a simplified example below is used to demonstrate how carbon emission influences decision-making.

It is assumed there is a demand to build a single span bridge with a general arrangement of 12m (length) x 12m (width) with 50 years of service life. The structure will be demolished at the end of its service life of 50 years. The superstructure is simply supported by concrete abutments at both ends.

From the optioneering stage, we will choose the preferred superstructure from the options below.
Option 1 - Concrete beams
Option 2 - Steel beams
Option 3 - Timber beam and deck.

we will calculate the carbon emission from its lifecycle of different options, the quantitative outcome will provide us the reference in decision-making from the carbon emissions perspective.

To keep the example simple enough to illustrate the framework proposed, the carbon content of different materials is under assumption basis. The breakdown of the lifecycle activities has been simplified.

Lifecycle asset management breakdown

Table 1. Carbon emissions source of the bridge at different lifecycle stages

Options	New installation		Operation/ maintenance	Demolition
	Material production	Construction		

Option 1	Concrete production/ transportation	Beam installation/ Concrete pouring/ Construction equipment operation	Maintenance free	Concrete structure demolition
Option 2	Steel components production/ transportation	Steel installation/ Construction equipment operation	Painting at 25 years	Steel structure demolition
Option 3	Timber components production/ transportation	Site installation/ Construction equipment operation	Major renewal at 25 years	Timber structure demolition

The quantified consumption of material and energy are shown in Table 2, Table 3 and Table 4 corresponding to each lifecycle stage.

It is assumed the concrete option is maintenance free in 50 years of service life.

It is also assumed all the structures are to be demolished at the end of the service life, even which is normally not the case in real life.

Table 2. New installation stage consumption

Options	**Concrete**	**Steel**	**Timber**	**Heavy fuel oil**	**Diesel**	**Electricity**
	(kg)	(kg)	(kg)	(litre)	(litre)	(kWh)
Option 1	126000	54000	-	40	10	108000
Option 2	-	90000	-	35	6	8000
Option 3	-	-	100000	25	6	7000

Table 3. Operation/maintenance stage consumption

Options	**Concrete**	**Steel**	**Timber**	**Heavy fuel oil**	**Diesel**	**Electricity**
	(kg)	(kg)	(kg)	(litre)	(litre)	(kWh)
Option 1	-	-	-	-	-	-
Option 2	-	90	-	-	5	2000
Option 3	-	-	10000	-	5	3000

Table 4. End of life demolition consumption

Options	**Material waste**			**Demolish energy**		**Transportation**
	Concrete	**Steel**	**Timber**	**Heavy fuel oil**	**Electricity**	**Diesel**
	(kg)	(kg)	(kg)	(litre)	(kWh)	(litre)
Option 1	126000	54000	-	8	21600	400
Option 2	-	90000	-	7	1600	180
Option 3	-	-	100000	5	1400	120

Embedded carbon emissions factors

The carbon emission factors are provided from the Ministry for the Environment report (Environment, 2020).

Table 5. Embedded carbon emission factors list

Items	**Materials**			**Energy**			**Waste**
	Concrete	**Steel**	**Timber**	**Heavy fuel oil**	**Diesel**	**Electricity**	**Construction/ Demolition**
Unit	kg	kg	kg	litre	litre	kWh	kg
Carbon emissions (kgCO_2-e/kg)	0.203	2.85	0.015	3.22	2.69	0.0977	0.14

Carbon emissions of three options and decision making

Following equation 1 above, the carbon emissions of three options are calculated and summarised below in Table 6.

By taking option 1 as an example,

- At the new installation stage, the carbon emission is,

$$\begin{aligned}
&126000(Concrete\ quantity) \times 0.203(Concrete\ emission\ factor)\\
&+54000(Steel\ quantity) \times 2.85(Steel\ emission\ factor)\\
&+40(Heavy\ fuel\ oil\ quantity) \times 3.2(Heavy\ fuel\ oil\ emission\ factor)\\
&+10(Diesel\ quantity) \times 2.69(Diesel\ emission\ factor)\\
&+108000(Electricity\ quantity) \times 0.0977(Electricity\ emission\ factor)\\
&= 190185kg_CO_2
\end{aligned}$$

- At the operation/maintenance stage, the carbon emission is, $0kg\_CO_2$ Maintenance free assumption as concrete.

- At the end of life demolition, the carbon emission is,

$$\begin{aligned}
&126000(Concrete\ quantity) \times 0.14(Waste\ construction/demolition\ emission\ factor)\\
&+54000(Steel\ quantity) \times 0.14(Waste\ construction/demolition\ emission\ factor)\\
&+8(Heavy\ fuel\ oil\ quantity) \times 3.2(Heavy\ fuel\ oil\ emission\ factor)\\
&+400(Diesel\ quantity) \times 2.69(Diesel\ emission\ factor)\\
&+216000(Electricity\ quantity) \times 0.0977(Electricity\ emission\ factor)\\
&= 28412kg_CO_2
\end{aligned}$$

- Total emissions of Option 1,

$$90185 + 0 + 28412 = 218597kg\_CO_2$$

Table 6. Carbon emissions of different options

Options	Carbon emissions of lifecycle stages			Total emissions
	New installation	Operation/maintenance	Demolition	
	(kg)	(kg)	(kg)	(kg)
Option 1	190185	0	28412	218597
Option 2	257410	465	13263	271139
Option 3	2281	457	14476	17213

Table 6 shows that Option 3 has the lowest total carbon emissions from its lifecycle among all the options, hence the timber beam option is the preferred by taking carbon emissions as the measure in this case.

CONCLUSIONS AND RECOMMENDATIONS

This paper discussed the framework to measure carbon emissions and how it can be used as a decision-making factor quantitatively within the asset management practice.

The effort to reduce the carbon emissions shall come along with the whole lifecycle of the structures from the decision making, all the way from the start of the asset creation to the end of its service life. The carbon emission is one of many factors in decision making, while its weight or contribution is to be further discussed.

The proposed framework is illustrated using a simplified example. The parameters used in carbon emissions calculations are to be investigated and updated to suit the specific environment. It is worth to set up a programme from the road authority for the standardised carbon emissions assessment. The quantified outcome will aid the decision-making process.

The proposed quantitative carbon emission calculation framework is suitable for,

- Whole of life asset management, for example the asset lifecycle carbon emission control.

and

- Specific stage asset management, for example in choosing a specific preferred option for a new structure, or for a structural rehabilitation.

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