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Contemporary Research Topics

work-based learning 4: Technology

November 2022

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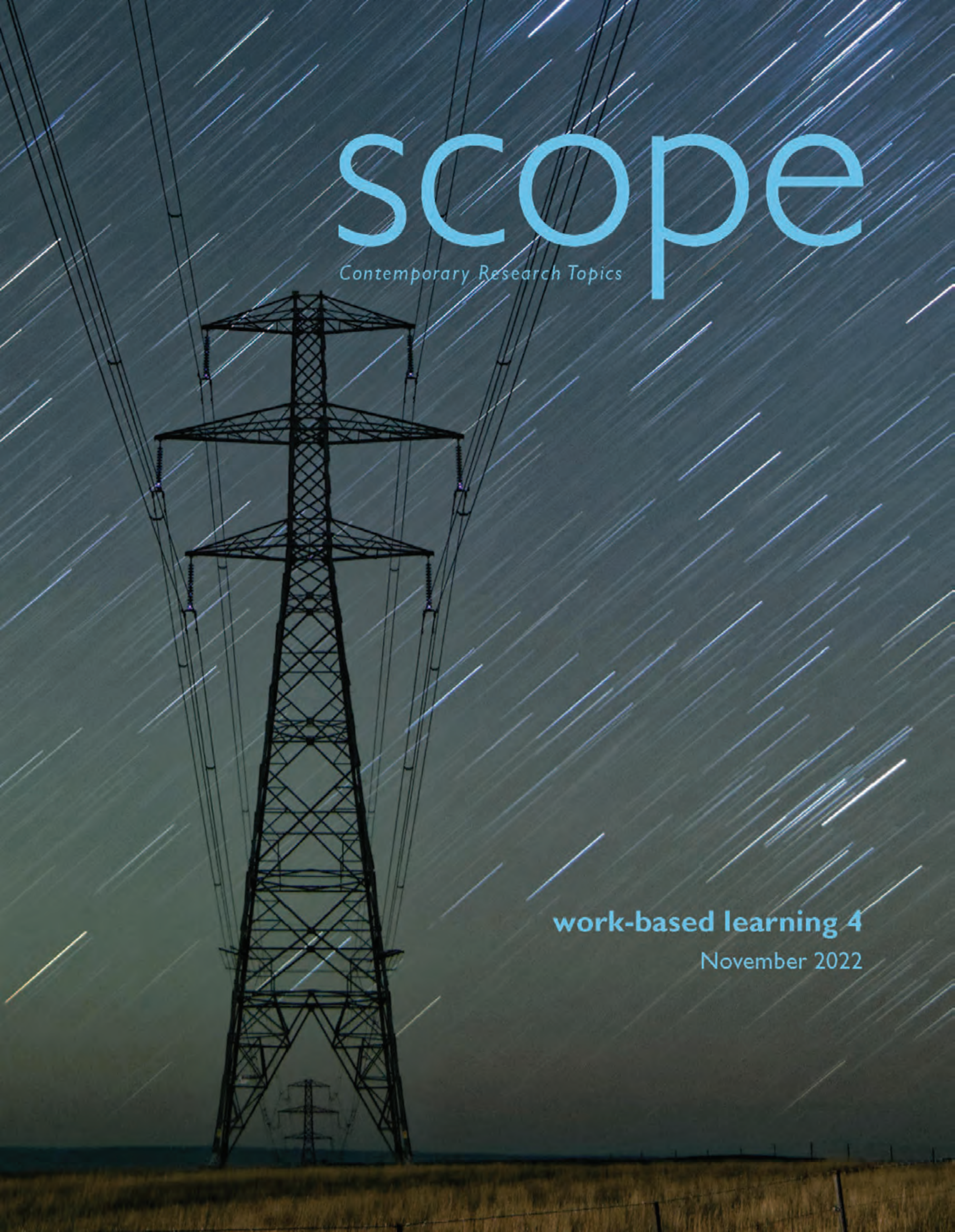

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This special issue of *Scope: Contemporary Research Topics (Work-based Learning)* on Technology focuses on emerging scientific and technological trends across a broad range of fields.

Scope: Contemporary Research Topics (Work-based Learning) focuses on contemporary research in assessment of prior learning; learning in, for, and about work, and professional practice. It is concerned with critical debate about practice, theory, and history, and their relationships as manifested in the experiences of learners, practitioners, and researchers in work-based learning and professional practice.

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High standards of writing, proofreading and adherence to consistency through the APA referencing style are expected. For more information, please refer to the APA Publication Manual, 7th edition; and consult prior issues for examples. A short biography of no more than 50 words; as well as title; details concerning institutional position and affiliation (where relevant); contact information (postal, email and telephone number) and ORCID number should be provided on a cover sheet, with all such information withheld from the body of the submission. Low resolution images with full captions should be inserted into texts to indicate where they would be preferred, while high resolution images should be sent separately.

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SCOPE (WORK-BASED LEARNING) SPECIAL ISSUE ON *TECHNOLOGY*

Hymie Abd-Latif
and Syed Faisal Hasan

Kia tau te rangimarie

With the growth of work-based learning and practitioner research, this *Scope (Work-based Learning)* special issue on *Technology* was initiated by whānau at Otago Polytechnic | Te Kura Matatini ki Otago who wanted a platform for technology research. This issue has been curated to feature a spectrum of work at the theory-practice nexus in areas ranging from material sciences in mechanics and building; to decision support systems, and to innovative tools for the workplace. In total, this special issue brings in research from six different disciplines, each presenting innovative research that deserves a wider audience. We are profoundly exhilarated to present the work of colleagues across the motu and world validating the strong and vigorous collaborations that exist. Authors and reviewers alike have responded with rich prose and reviews uplifting the quality of the articles you are about to read. He tino pai tō mahi.

In a time when the world is slowly recovering from the COVID-19 pandemic, with an unprecedented demand for technological innovation and a workforce with relevant technical skill sets, the research published in this journal is highly relevant. Rozado et al., whose article is a timely contribution, provide directions to employers, academic institutions, and learners towards developing skills which are most relevant to the job market right now. Masood et al. help educators and practitioners to understand different classes of prefabricated construction materials so that they can align their learning outcomes better. Gabriel et al. investigate smart traffic light control systems at an intersection in Invercargill. Their proposed improvements will avoid risks and reduce delays. Conducting experiments to acquire acoustic emission signals, May et al. then apply empirical mode decomposition method to eliminate noise. McKinlay presents a bespoke design of the compact upright weaving loom. Cherrington et al. look at data analytic techniques to help managers make short-term and long-term decisions into reducing campus carbon footprints.

In conclusion, we hope that through this special issue our kaimahi and their affiliations around the world will be able to engage in trans-disciplinary research where the role of technology is instrumental.

Nāku iti nei, nā

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Article

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DESIGN AND IMPLEMENTATION OF A SMART TRAFFIC SIGNAL CONTROL SYSTEM

Carlo M. Gabriel and Jaime C. Arpasi

ABSTRACT

Transport and road traffic demand has caused signs of congestion, delays, and accidents in the last two decades, particularly in developing cities, mainly during peak hours. Hence, a multidisciplinary effort (for example, the improvement of driving habits, the provision of better infrastructure and traffic management measures, and the rationalisation of the use of public roads) is needed. This project proposed the design and implementation of a smart traffic light control system to improve the vehicular circulation of Queens Drive – Layard Street intersection, especially during peak hours. Finally, it evaluated the factors generating problems and social impact (for example, lost man-hours, environmental pollution, and accidents) to propose strategies to improve the traffic flow, reduce operational conflict, and provide a safer environment for the community. From the analysis and simulation carried out with the VISSIM software during rush hour at the intersection with traffic lights, it was found that the number of vehicles in the queue was reduced from 351 to 270 in the six possible movements within the intersection. By reducing the vehicles in the queue, pollution emissions are also reduced (297.1 g/h CO emissions and 57.9 g/h NO emissions). Finally, 270 vehicles queuing generate an extra cost in fuel, although in less quantity, reducing consumption from 17.8 to 16.7 L/h. Therefore, the proposed situation has reduced the delay and number of vehicles, yet the service level remains the same as the current situation. In addition, the proposed case includes improvements in horizontal and vertical signage, which will help mitigate risks and reduce unnecessary delays.

INTRODUCTION

Traffic congestion is a global problem that leads to delays, time loss, crashes, energy consumption, human stress, and pollution among other issues (Transportation Research Board, 2000). According to the Road Safety 2020 Annual Report, New Zealand had one of the largest increases (10.9 per cent) in the number of road fatalities in 2018 compared to the average from 2019 to 2021. In addition, New Zealand had a considerable increase in the total number of pedestrians killed on the road (11 per cent) between 2010 and 2018 (IRTAD, 2020). Therefore, in order to decrease car crashes and traffic congestion, it is necessary to manage the traffic flow in the best possible way and to develop road safety solutions through the use of modern technology and applications.

Road intersections offer research potential in traffic flow, especially in a city such as Invercargill with massive potential for improvement in terms of traffic and transport. Invercargill is located in the Southland region, with a population of approximately 57,100 inhabitants. In recent years, road demand has grown due to the increase in population and in private vehicle usage. It is perceived that the road design and traffic road devices in areas of high concentration of travel (schools, offices, stadiums, and other infrastructures) during peak hours do not satisfy the demand for transport which has resulted in increases in travel time, delays, accidents, and environmental problems.

In the specific case of the Queens Drive – Layard Street intersection in Invercargill, it has been found that different sites such as James Hargest College, Lees Street Kindergarten, and the Waihopai Bowling Club, are generating a lot of movement of people and vehicles. As a consequence, different problems can be identified affecting the community and generating high rates of traffic congestion and social impact (lost man-hours, accidents, pollution), mainly during peak hours (Figure 1).

Figure 1. Development Site Location (Google, 2021).

During the past two decades, an increase in demand for transport and road traffic has caused, particularly in developing cities, signs of congestion, delays and accidents, mainly during peak hours. Therefore, a multidisciplinary effort that includes the improvement of driving habits, the provision of better infrastructure and traffic management measures (management of the supply), and the rationalisation of the use of public roads (demand management) is urgently needed. Hence, this project proposed the design and implementation of a smart traffic light control system to improve the vehicular circulation of the Queens Drive – Layard Street intersection. Further, it evaluated the factors generating problems and social impact to propose strategies to improve the traffic flow and reduce the operational conflict and to provide a safer environment for the community. Finally, the project evaluated the implementation of a traffic light system to counteract the factors that have been generating problems with social impact to propose measures that speed up vehicle flow mainly during peak hours.

METHOD

This study followed quantitative descriptive research methodology. A survey was administered to determine the traffic volumes in terms of walking paths, cycling, parking vehicles, and right-left turning. The data collected was calculated and analysed using the operational analysis method for signalised intersections (Antunez, 2019).

A survey was administered during busy hours to collect the data from the Queens Drive intersection with Layard Street (for example traffic volumes, walking paths, cycling, parking vehicles, right-left turning, and so on). The queue length on each road (Queens Drive and Layard Street), total phases, capacity, and other variables needed to determine the cycle time for the smart traffic light system in the intersection were also examined.

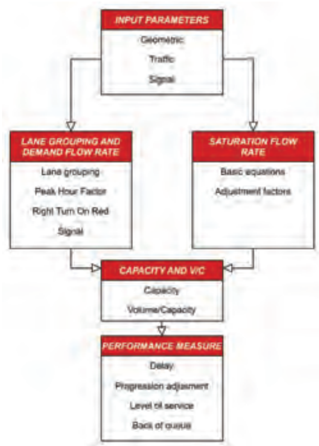


Figure 2. Operational analysis methodology for signalised intersections (Antunez, 2019).

A. Description of the methodology

The methodology (Figure 2) begins by recognising the geometric conditions and volumes at the intersection of study (Queens Drive – Layard Street), as well as determining the 'conflictive transit' which is represented by all the movements on the secondary road and the right-hand turn movement from the main road. It is necessary to know the capacity of the spaces in the main traffic stream to accommodate each of the movements under study that will use these spaces. Finally, the capacities found must be adjusted due to the impedance effects of right turners from major streets and the use of the shared lanes.

B. Input parameters

Table 1 provides a summary of the input information required to perform an operational analysis for the Queens Drive – Layard Street intersection. This information forms the basis for selecting values and computational procedures in the modules that were developed specifically for the calculation of cycle time. The data required is detailed and varied and falls into three main categories: geometric, traffic, and signage.

TYPE OF CONDITION	PARAMETER
GEOMETRIC CONDITIONS	Area type Number of lanes, N Average lane width, W (m) Grade, G (%) Existence of exclusive LT or RT lanes Length of the storage bay, LT or RT lane, Ls (m) Parking
TRAFFIC CONDITIONS	Demand volume by movement, V (veh/h) Peak-hour factor, PHF Percent heavy vehicles, HV (%) Local buses stopping at the intersection, N_b (buses/h) Parking activity, N_m (number of manoeuvers/h) Arrival type, A_T The proportion of vehicles arriving on green, P Approach speed, S_a (km/h)
SIGNALISATION CONDITIONS	Cycle length, C (s) Green time, G (s) Yellow-plus-all-red change and clearance interval Actuated or pre-timed operation Pedestrian push-button Minimum pedestrian green, G_p (s) Phase plan Analysis period, T (h)

Table 1. Input data needs for each analysis lane group (Antunez, 2019).

C. Traffic microsimulation modeling

The general process for developing and applying a microsimulation model to a traffic analysis problem consists of seven main tasks as shown in Figure 3.

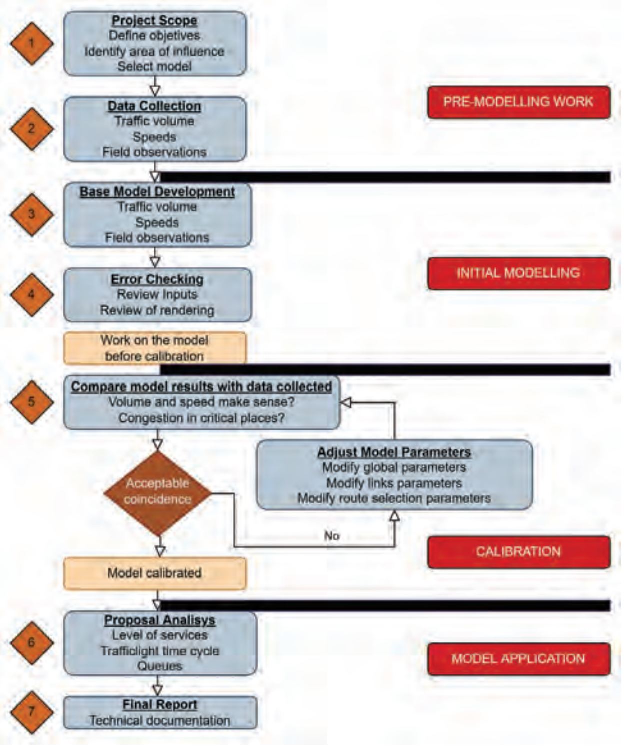


Figure 3. Traffic Analysis Toolbox Volume III: Guidelines for Applying Traffic Microsimulation Modelling Software (Haridas, 2020).

RESULTS

A. Traffic survey analysis

From the information processed on Thursday, July 9, 2021, the following peak hours were identified: 8:30 a.m. to 9:30 a.m. (morning shift), 3:15 p.m. to 4:15 p.m. (afternoon shift), and from 5:00 p.m. to 6:00 p.m. (night shift).

Of the three peak hours of the day, the peak hour that obtained the highest pedestrian volume during the day was chosen for the analysis. According to this, in the morning vehicular peak hour, a total of 2138 vehicles passed through the intersection and 158 pedestrians, while in the afternoon rush hour a total of 1985 equivalent vehicles and 125 pedestrians passed through.

B. Peak hour

According to the vehicle composition of all those who passed through the intersection, the predominant vehicle was cars (1881), which represented 88 per cent of the morning rush hour volume.

According to the pedestrian composition of the traffic survey, 98 pedestrians crossed the intersection during the morning peak hour and were mostly students and workers from the James Hargest School.

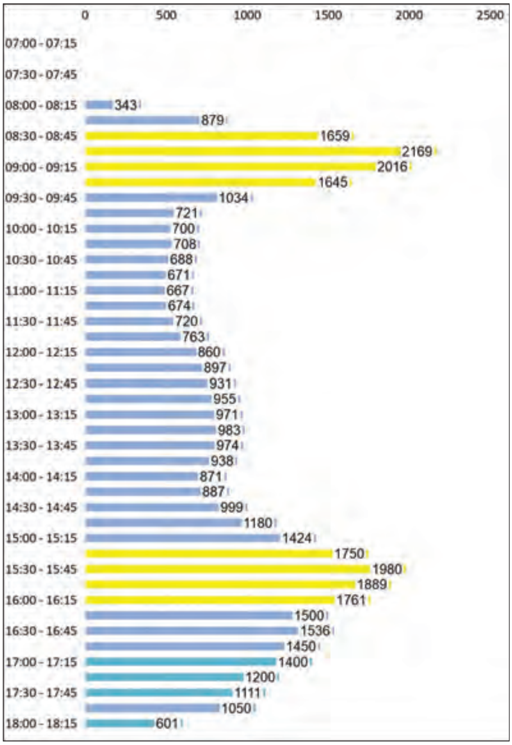


Figure 4. Vehicle Maximum Demand Chart
(Periods of maximum demand per point hour intersection: Queens Drive – Layard Street).

Layard Street approach (East → West)

From the total of vehicles displaced by this approximation, 52 private vehicles (cars), two vehicles for the transportation of people, five cargo transport vehicles, and three motorcycles; making a total of 410 vehicles that took to the UCP equivalency representing a total of 332 cars.

Two movements are generated: the first is the turn to the right (movement 30) with 251 vehicles (205 cars) representing 13.1 per cent and the second to the left (movement 32) with 159 vehicles (127 cars) that represent 8.1 per cent of the vehicle volume in the hour of maximum demand of the morning shift.

A total of 71 pedestrians from North-South and South-North crossed this approach (movements P1 and P2).

Queens Drive approach (North → South)

Of the total vehicles displaced by this approximation, 191 private vehicles (cars), 69 vehicles for transportation of people (67 rural vans, 2 minibuses, and 0 buses), 14 cargo transportation vehicles, 43 minor transportation vehicles (bicycles) and 14 motorcycles; making a total of 724 vehicles that, taken to the UCP equivalence, represent a total of 658 cars.

Three movements are generated in this approach: the first is the front turn (movement 10) with 601 vehicles (553 cars) representing 35.4 per cent. The second to the right (movement 11) with 120 vehicles (104 cars) represents 6.6 per cent and the third U-turn (movement 13) with 3 vehicles (2 cars) represents 0.1 per cent of the vehicle volume in the hour of maximum demand of the morning shift.

A total of 75 East-West and West-East pedestrians crossed this approach (movements P3 and P4).

Queens Drive approach (South → North)

Of the total vehicles displaced by this approximation, 146 private vehicles (cars), 73 vehicles of transportation of people (73 rural vans, 0 minibuses, and 0 buses), 7 vehicles of cargo transportation, 408 small transportation vehicles (moto-taxi), and 6 motorcycles; making a total of 640 vehicles that, taken to the UCP equivalence, represent a total of 569 cars.

Three movements are generated: the first is the front turn (movement 21) with 433 vehicles (391 cars) representing 20.05 per cent. The second from the left (movement 22) with 147 vehicles (129 cars) representing 8.26 per cent and the third U-turn (movement 23) with 60 vehicles (50 cars) represents 3.18 per cent of the vehicle volume in the hour of maximum demand of the shift the following day.

C. Cycle time calculation

In an intersection with traffic lights, where all the vehicles continue straight ahead, the rates would be maximum flow rates, at approximately equal intervals. However, at the Queens Drive – Layard Street intersection, the situation is more complex due to the presence of heavy vehicles and turn movements to the left and right.

Adjustment for heavy vehicles

According to Highway Capacity Manual (2000), the heavy-vehicles factor (F_{HV}) represents the impact that heavy vehicles have on passenger cars. Heavy vehicles are defined as those with more than four tyres touching the pavement. The heavy-vehicles factor accounts for the additional space occupied by these vehicles and for the difference in operating capabilities of heavy vehicles compared with passenger cars.

Heavy or commercial vehicles (trucks and buses mostly), due to their longer length and less acceleration power than cars, need more time to clear the intersection.

The following data (PC and PB) in Table 2 was extracted from the traffic survey. Equivalent automobiles commonly used for both trucks (EC), and for buses (EB), vary from 1.4 to 1.6. In this research an average value of 1.5 was considered.

DATA		Queens Drive – Layard Street Intersection
PC	% Trucks in the intersection.	4%
PB	% Buses in the intersection.	5%
EC	Cars equivalent to a Truck.	1.5 cars/truck
EB	Cars equivalent to a Bus.	1.5 cars/truck
Heavy Vehicles Factor (F_{HV})		**0.96**

Table 2. Adjustment for heavy vehicles factor (F_{HV}) results.

Peak-Hour Factor

According to Antunez (2019), this approach involves a study of the entire peak hour but divides it into four 15-minute analysis periods. This analysis allows the account for queues that carry over the next analysis period. Therefore, when demand exceeds capacity during the study period, a more accurate representation of the delay experienced during the hour can be achieved by this method.

$$\text{PHF} = \frac{VHM}{4 \times V_{15}} \qquad (1)$$

PHF: Peak Hour Factor

VHM: Volume per hour of maximum demand

V_{15}: 15-minute traffic flow more loaded

TIME	No. of Vehicles
08:00 - 08:15	477
08:15 - 08:30	537
08:30 - 08:45	*633*
08:45 - 09:00	511
08:00 - 09:00	*2158*

$$FHP = \frac{2158}{4 \times 633}$$

FHP = 0.9

Equivalent car flows of straight crossing

On the other hand, it is required to have factors for the movements of turn (right and left turns), since these manoeuvres generally consume more time than vehicles that continue straight through the intersection.

The conversion factors that are used to convert cars that turn left or right to equivalent cars that continue straight are calculated using the following tables.

Left Turn (E_v Left)

The conversion factors take into account the greater time consumed when turning due to the presence of vehicles.

(*) For vehicles entering from Layard Street direction E>W, there are no opposite traffic lines, so the E_v for left-hand turns would be 1.1. (E_v = 1.1).

(**) For vehicles entering from Queens Drive heading N>S, there are 03 opposite lines with a traffic flow of approximately 600 vehicles, so the E_v for left-hand turns from Queens Drive N>S would be four. (E_v = 4).

For vehicles entering from Queens Drive in the S>N direction, there are no left-hand turns as it is a "T" intersection, so the E_v for left-hand turns does not exist (zero).

Opposite Flow (vehicle/h)	Number of opposing lanes		
	1	2	3
0 (*)	*1.1*	*1.1*	*1.1*
200	2.5	2	1.8
400	5	3	2.5
600 (**)	*10*	*5*	*4*
800	13	8	6
1000	15	13	10
>1200	15	15	15

Table 3. Equivalent direct cars for left-hand turns (Antunez, 2019).

Right Turn (E_v Right)

Here, the conversion factors take into account the longest time consumed when turning due to the presence of pedestrians.

(***) For vehicles entering from Queens Drive in the N>S direction, according to the pedestrian counts in the traffic survey, it was possible to count around 200 pedestrians most of them students and staff of the James Hargest School.

For vehicles entering from Queens Drive in the S>N direction, there are no right-hand turns as it is a "T" intersection. Therefore, the E_v for right-hand turns does not exist (zero).

Pedestrian volume at the closest crossing (pedestrian/h)	Equivalent
None (0)	1.18
Low (50)	1.21
(***) Moderate (200)	*1.32*
High (400)	1.52
Extreme (800)	2.14

Table 4. Equivalent direct cars for right-hand turns (Antunez, 2019).

Table 5 shows the factors from every access to the intersection obtained from the previous tables.

	Layard Street E>W	Queens Drive N>S	Queens Drive S >N
Heavy Vehicles Factor (F_{HV})	0.96	0.96	0.96
Peak-Hour Factor (PHF)	0.90	0.9	0.90
Left Turn Factor (E_v Left)	1.10	4.00	0
Right Turn Factor (E_v Right)	1.32	0	1.32

Table 5. Resume of factors for Q_{ADE} calculation.

In this way, the volume per hour of maximum demand ($VHMD$) was converted to direct automobile flows, using the following expression.

$$Q_{ADE} = \frac{VHMD}{FHP}\left(\frac{1}{F_{HV}}\right)(E_v) \qquad (2)$$

Q_{ADE}: Equivalent car flows of straight crossing.
$VHMD$: Volume per hour of maximum demand
F_{HV}: Adjustment for Heavy Vehicles
FHP: Peak Hour Factor
E_v Equivalent car flows for right and left turns

Table 6 shows the values obtained so far for the 03 vehicular accesses to the intersection of Queens Drive – Layard Street in equivalent car flows of straight crossing.

	Layard Street E>W (no. of vehicles)	Queens Drive N>S (no. of vehicles)	Queens Drive S>N (no. of vehicles)
Volume ADE Left	377	989	0
Volume ADE Right	121	0	570
Volume ADE Straight	0	755	614
Volume ADE TOTAL	**498**	**1744**	**1184**

Table 6. Results for Q_{ADE} calculations.

D. Phase change interval

The purpose of the phase change interval is to alert users of a change in the assignment of the right to use the intersection. To calculate the phase change interval, the time driver reaction, deceleration time and space and the time needed to clear the intersection were considered.

The formula where the term $(v/2a)$ represents the time necessary to travel the stopping distance with deceleration 'a' and velocity 'v', and the term $(W+L)/v$ is the time to cross the intersection. The first two terms, $t+v/2a$, identify the interval of amber change, and the third term, $(W+L)/v$, is associated with the interval of change in everything red.

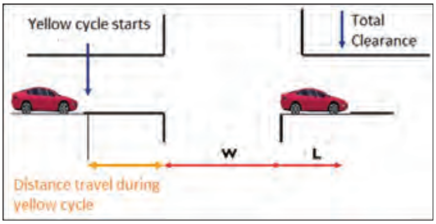


Figure 5. Distance to cross an intersection.

$$Y = \left(t + \frac{v}{2a}\right) + \left(\frac{W + L}{v}\right) \quad (3)$$

(A_i) YELLOW + (TR_i) ALL RED

Y: Phase shift interval, yellow plus all red (s)
t: Driver perception-reaction time (usually 1.00 s)
v: Car approach speed (m/s) (v=50 km/h in Invercargill CBD)
a: Deceleration rate (usual value 3.05 m/s^2)
W: Intersection width (m)
L: Vehicle length (suggested value 6.10 m)
A_i: Yellow/Amber Interval of time (s)
TR_i: Total Red Interval of Time (s)

Table 7 shows the values obtained for the 03 vehicular accesses to the intersection Queens Drive – Layard Street for the Phase Change Interval calculation.

Calculation determines one (01) traffic light phase Layard Street, in the same way 01 phase for Queens Drive, each one with their respective times of yellow and all red necessary for the pass between phases. Finally, the total lost time is calculated, adding the Phase Shift Interval (Y) of both phases, which results in the Total Lost Time (L_t) of 10 seconds of non-effective time or non-green time, which was used for the following calculations.

		Layard Street E>W	Queens Drive N>S	Queens Drive S>N
t	Driver perception time	1.00s	1.00s	1.00s
v	Car approach speed	13.80m/s	13.80m/s	13.80m/s
a	Deceleration rate	3.05m/s^2	3.05m/s^2	3.05m/s^2
W	Intersection width	19.3m	16.7m	16.7m
L	Vehicle length	6.10m	6.10m	6.10m
A_i	Yellow Interval of time	3.3s	3.3s	
TR_i	All Red Interval of time	1.8s	1.6s	
		Phase 01	***Phase 02***	
Y	Phase shift interval	5.1s	4.9s	
L_t	Total Lost Time (Yellow+All Red)	***10.0s***		

Table 7. Results for phase change interval.

E. Maximum vehicular flow ratio

According to Antunez (2019), we need to calculate the optimal cycle time or minimum cycle time in each intersection, allowing all traffic in waiting for the green signal to go through the intersection. To do this, we must find the Y_i (Maximum Vehicular Flow Ratio) values of Queens Drive (N>S) and Layard Street (E>W). The Y_i value is equal to the relationship between the flow existing in the lane divided by its saturation flow.

$$Y_i = \frac{Q_{imax}}{S} \quad (4)$$

Y_i: Maximum vehicular flow ratio
Q_{imax}: Maximum or critical adequate flow (Q_{ADE}) per lane (vehicles/h/lane)
S: Saturation flow (1750 vehicles/h/lane)

(*) the saturation factor (S=1750 vehicles/h/lane) is recommended in the Highway Capacity Manual, for signalised intersections.

		Queens Drive N>S	Layard Street E>W
Q_{imax}	**Maximum adequate flow**	989 vehicles/h/lane	377 vehicles/h/lane
S	**Saturation flow**	1750 vehicles/h/lane	1750 vehicles/h/lane
Y_i	**Maximum vehicular flow ratio**	**0.57**	**0.22**

Table 8. Maximum vehicular flow ratio (Y_i).

F. Total Cycle Length

Based on field observations and simulation of a wide range of traffic conditions, the delay minimum of all vehicles at an intersection with traffic lights can be obtained for an optimal cycle time.

$$C_0 = \frac{1.5L_t + 5}{1 - \Sigma_{i=1}^{\phi} Y_i} \quad (5)$$

C_o: Optimal cycle time (s)

L_t: Total time lost per cycle

Y_i: Maximum value of the ratio between the current flow and saturation.

φ: number of phases

Consequently, the effective total green time for the intersection can be determined:

		Phase 01	Phase 02
Lt	**Total Lost Time (Yellow+All Red)**	10s	
Y_i	**Maximum vehicular flow ratio**	0.21	0.17
φ	**Number of phases**	2.0 phases	
C_o	**Optimal Cycle Time (Green+Yellow+All Red)**	91.3s	

Table 9. Results for optimal cycle time.

$$g_T = C_o - L_t \quad (6)$$

g_T: Total green time per cycle

C_0: Optimal cycle time (seconds)

L_t: Total time lost per cycle

C_0	**Optimal Cycle Time (Green+Yellow+All Red)**	91.3s
Lt	**Total Lost Time**	10s
g_T	**Green effective time**	**81.3s**

G. Green effective time per phase

Finally, the distribution of the total effective green time in the phases was determined with the following formula.

$$g_i = \frac{Y_i}{\Sigma_{i=1}^{\varphi} Y_i}(g_T) \quad (7)$$

g_i: Green time relative per phase

Y_i: Maximum vehicular flow ratio

g_T: Total green effective time

φ: number of phases

		Time (second, s)
Yi_1	**Maximum vehicular flow ratio-Phase 01**	0.21
Yi_2	**Maximum vehicular flow ratio-Phase 02**	0.17
g_T	**Green effective time**	81.3
g_{i1}	**Green time for Phase 01**	44.9
g_{i2}	**Green time for Phase 02**	36.3

Table 10. Results for Green time relative per phase.

H. Time distribution diagram per phase in Peak Hour

As demonstrated in the calculation, theoretical cycle time required for the correct movement of vehicles is shown in Figure 6.

This means, that as long as the optimal theoretical conditions are presented at the intersection of Queens Drive – Layard Street, there are no obstacles to the passage of vehicles and their flow is continuous, the times that are theoretically obtained should be sufficient to satisfy the traffic demand.

G1 = 45s	A1 = 3s	Tr = 2s	C0=91
G2 = 36s	A1 = 3s	Tr = 2s	

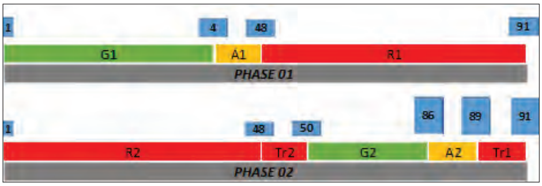


Figure 6. Time distribution diagram.

DISCUSSION

The results indicate that the Queens Drive – Layard Street intersection experiences traffic congestion at different times during the day. The factors considered in the study were the time of the day, types of vehicles, and road infrastructure.

The time of the day is one of the many factors that affect traffic congestion. Drivers often tend to overtake and speed up when in a hurry. According to Green (2003), in an extensive analysis using Australian crash data from 1994 to 1998, related crashes were observed during the afternoon and on weekends, suggesting a relationship with late night and drinking. However, as shown in Vehicle Maximum Demand Chart there is not much difference in traffic volume for the daily morning routine (8:30 a.m.–9:30 a.m.) and afternoon (3:30 p.m.–4:30 p.m.).

According to the evaluation carried out on the operational behavior of the intersection under study, it was verified that one of the main factors that have been generating traffic congestion is right-hand turns. However, all right-hand turns (three turns) are currently being made without supervision or control, causing vehicles to be stationary in the central part of Queens Drive and obstruct the passage of cyclists.

Another factor generating traffic congestion is the deficiencies in the geometric road design on Layard Street. This road has only one lane entrance, while the vehicular flow that circulates along Queens Drive (three lanes) is entering a single lane from Layard Street; for this reason, the intersection area is currently being used as a transition zone from three to one lane, where a bottleneck has been generated, causing the formation of queues within the intersection.

In relation to right-hand turns, the American Association of State Highway and Transportation Officials (AASHTO), reported that right-hand turns reduce the capacity of intersections and slow the flow of vehicles. Hence, it is recommended that drivers try to avoid them through other alternatives such as indirect left-hand turns, roundabouts, or traffic signals, among others.

The operational problems of the intersection of Queens Drive and Layard Street lead to the degradation of the quality of urban life, due to the impacts derived from the traffic identified in the field.

A. Project design and approach

For this project, civil works such as underground canalisation and ramps will be carried out. Works corresponding to traffic lights and signalling will be carried out at the intersection of the canalisation in tracks and sidewalks, installation of boxes and bases for the traffic light poles.

Location			Poles (unit)		Traffic Light (unit)		Controller (unit)
Line	Bound	Approach	Flag	Post	Vehicular	Pedestrian	
Queens Drive	N-S	North	-	3	4	-	-
	S-N	South	1	-	3	-	1
Layard Street	E-W	East	1	-	2	-	-
TOTAL			2	3	9	0	1

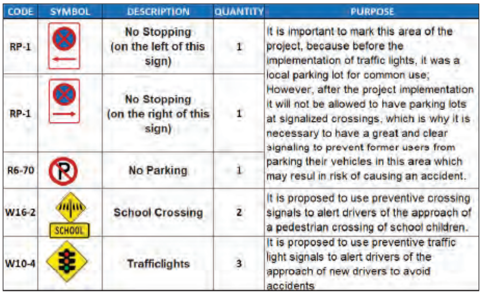
Table 11. Traffic light distribution.

Installation of three pedestal posts and two flag posts, nine vehicular traffic lights, and one controller traffic light as detailed in Table 11 is proposed.

In the proximity to each pedestal post and at the interconnection points, we propose building six junction boxes the same that will be connected between pipes under the road, and will serve for the corresponding electrical installations (Figure 7).

Figure 7. Traffic lights positioning.

Traffic signs are another parameter within traffic engineering whose objective is to use different colors, shapes, images, and signs to help road ordering both in urban areas and highways. It is proposed the following traffic signs, listed and explained in Figure 8, be put in the different locations as specified in Figure 9.



CODE	SYMBOL	DESCRIPTION	QUANTITY	PURPOSE
RP-1		No Stopping (on the left of this sign)	1	It is important to mark this area of the project, because before the implementation of traffic lights, it was a local parking lot for common use; However, after the project implementation it will not be allowed to have parking lots at signalized crossings, which is why it is necessary to have a great and clear signaling to prevent former users from parking their vehicles in this area which may resul in risk of causing an accident.
RP-1		No Stopping (on the right of this sign)	1	
R6-70		No Parking	1	
W16-2	SCHOOL	School Crossing	2	It is proposed to use preventive crossing signals to alert drivers of the approach of a pedestrian crossing of school children.
W10-4		Trafficlights	3	It is proposed to use preventive traffic light signals to alert drivers of the approach of new drivers to avoid accidents

Figure 8. Traffic signs proposal.

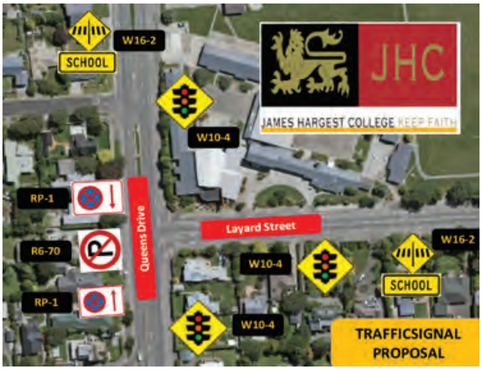


Figure 9. Location of traffic signs.

B. Standard time cycle during no peak hours/regular hours

Based on the traffic survey, the low number of vehicles entering the intersection from Layard Street is approximately two to three vehicles every 15 minutes during non-peak hours. It allows proposing a Standard Cycle Time during regular hours or no peak hours (9:30 a.m.–3:00 p.m. and 4:00 p.m.–8:30 a.m.) that will offer a permanent green for both directions of Queens Drive and a permanent red on Layard Street as shown in Figure 10.

According to the traffic survey, the entry of vehicles through Layard Street is low during non-peak hours (around two to three vehicles every 15 minutes). However, eventually, vehicles will come and enter the intersection from Layard Street (East-West).

In this sense, the implementation of an electromagnetic loop is proposed to detect the presence of vehicles on Layard Street which will be in the Standard Cycle Time Non-Peak Hours, giving a time of 10 seconds to release the Layard Street vehicles input.

The Activated Cycle Time (Figure 11) will occur when a vehicle is positioned on top of an electromagnetic sensor to pass the traffic flow of Layard Street. This vehicle will wait for 10 seconds and then will have 10 seconds to cross, after this, the cycle time will return to the Standard Cycle Time Non-Peak Hours until the next vehicle.

C. Calculated time cycle during peak hours

The traffic light times for the Calculated Time Cycle during peak hours (Figure 12) were determined based on the behaviour of the flow of vehicles and pedestrians performed in the Cycle time calculation, in order to avoid conflicts between vehicles when turning.

Likewise, various parameters were used to obtain optimal road capacity for each access and the shortest delay time at the intersection during peak time.

Morning Peak Hour: 8:30–9:30 a.m.

Afternoon Peak Hour: 3:00–4:00 p.m.

Figure 10. Standard time cycle diagram during regular hours.

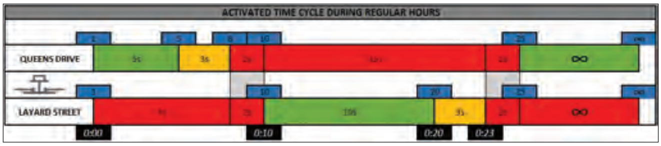


Figure 11. Activated time cycle diagram during regular hours.

G1 = 45s	A1 = 3s	Tr = 2s	C0=91
G2 = 36s	A1 = 3s	Tr = 2s	

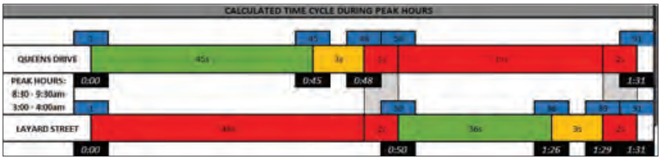


Figure 12. Calculated time cycle diagram during peak hours.

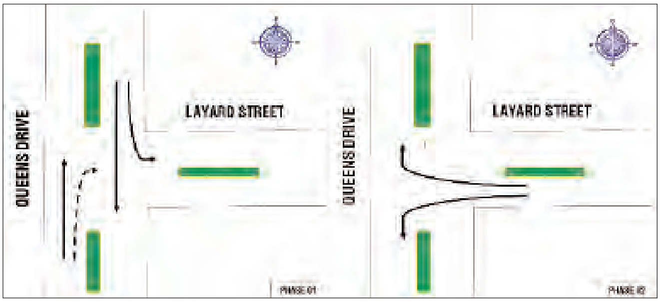


Figure 13. Phase diagrams.

Figure 12 shows the traffic light plan with its cycle (green, amber, and red); the electromagnetic loops will not be active during peak hours.

The Traffic Light Plan proposed with the Cycle Time of 91 seconds, will regulate the vehicular movement through two different states of the traffic light, as shown in Figure 13.

D. Simulation

The intersection simulation was carried out with the support of VISSIM software, with the purpose of presenting the intersection operation. VISSIM is a microscopic modeller that uses the algorithms included in the 2000 HCM of the Transport Research Council (Antunez, 2019). VISSIM's strength is its ability to optimise the scheduling of traffic light times and phases of isolated intersections, and the operation of networks and corridors. It also allows estimating the service levels representative of the functionality and operation of a road network.

Scope of the simulation

Traffic simulation is a tool widely used by traffic engineers to evaluate the behavior of the road due to possible modifications in vehicular traffic, alternative signalling configurations, and the construction of new roads.

An identical scenario was created in terms of road infrastructure, vehicular traffic and pedestrian access to the James Hargest school, and road marking of the intersection in order to create a model that simulates all possible factors that directly or indirectly affect traffic in Queens Drive – Layard Street.

Simulation of the current situation

The interaction between traffic volumes and geometric conditions of the intersection of Queens Drive – Layard Street was represented in a model, in order to know the operational characteristics and the value of the different performance indicators.

The simulation of the current situation was carried out considering the vehicular flows of the morning rush hour on Thursday 7 August 2021, where 2138 vehicles' Conversion Pattern Unit (CPU) and a circulation speed of 50 km/h were recorded according to the observations and data collection at the intersection under study.

From the simulation of the current situation, the generation of delays and queues in the turns to the right was identified; in addition, right-hand turns from Queens Drive into Layard Street are made at the discretion of drivers, which could lead to accidents if not controlled.

Table 12 shows the average indicators of about 10 simulations carried out during the rush hour.

- According to the traffic survey, there are 2138 vehicles passing through the intersection, of which 351 vehicles are queuing in the six possible movements within the intersection.
- These 351 vehicles stopped in queues still generate pollution that accumulates in the environment of the intersection where there is a large number of schoolchildren (328.9 g/h CO Emissions and 64.0 g/h NO Emissions).
- Finally, 349 vehicles queueing use extra fuel, due to the vehicles still running but stopped by congestion (17.8 L/h).

Simulation of the proposed situation

The projected situation will be simulated to consider implementing traffic lights at the intersection of Queens Drive – Layard Street in order to optimise the flow of the traffic network and thus clearly identify problems related to road infrastructure.

From the comparison of the level of service obtained in the current situation, it improves with the projected situation (with a traffic light intersection) and does not suffer major changes in Intersection Capacity Utilisation (ICU) service levels. However, the implementation of traffic lights give a slightly lower service level. In terms of delays, it increases the safety of right turns by having an exclusive time for the crossing.

UNSIGNALISED INTERSECTION						
Movement	Queue (m)	Queue Length Max	Vehicles	CO Emissions (g/h)	NO Emissions (g/h)	Fuel Consumption (L/h)
Queens NS - Queens NS	7.8	38.7	93	55.6	10.8	3.0
Queens NS - Layard	7.8	38.7	53	97.0	18.9	5.3
Layard - Queens NS	1.6	50.9	47	48.4	9.4	2.7
Layard - Queens SN	1.6	50.9	13	16.6	3.2	0.8
Queens SN - Layard	0.5	26.9	109	57.4	11.2	3.0
Queens SN - Queens SN	0.5	26.9	36	53.9	10.5	3.0
			351	**328.9**	**64.0**	**17.8**

Table 12. Simulation results – no traffic light signals.

SIGNALISED INTERSECTION						
Movement	Queue(m)	Queue Length Max	Vehicles	CO Emissions (g/h)	NO Emissions (g/h)	Fuel Consumption (L/h)
Queens NS - Queens NS	10.1	37.6	72	46.3	9.0	2.7
Queens NS - Layard	10.1	37.6	41	88.0	17.1	4.9
Layard - Queens NS	1.0	35.8	35	45.5	8.9	2.7
Layard - Queens SN	1.0	35.8	10	14.7	2.9	0.8
Queens SN - Layard	0.4	20.5	84	55.5	10.8	2.9
Queens SN - Queens SN	0.4	20.5	28	47.1	9.2	2.7
			270	**297.1**	**57.9**	**16.7**

Table 13. Simulation results – with traffic light signals.

From the simulation of the proposed situation with traffic lights, there is greater order and fewer queues in the right-hand turns. Additionally, right-hand turns from Queens Drive to Layard Street are made at the discretion of traffic lights, which could reduce accidents due to human error.

Table 13 shows the average indicators of about 10 simulations performed during rush hour at the intersection with traffic lights.

- The number of vehicles in the queue was reduced from 351 to 270 in the six possible movements within the intersection.
- By reducing the vehicles in the queue, pollution emissions are also reduced (297.1g/h CO emissions and 57.9g/h NO emissions).
- Finally, 270 vehicles queuing generate an extra cost in fuel, although in less quantity, reducing consumption from 17.8 to 16.7 L/h.

CONCLUSION

From the analysis carried out with the VISSIM software, it was found that the proposed situation has reduced the delay and vehicles, and the service level remains the same as the current situation. On the other hand, it should be noted that the proposed situation includes improvements in horizontal and vertical signage that influence avoiding risks and reducing unnecessary delays. Implementing a new monitoring study six months after the improvement proposals have been implemented, in order to optimise traffic light cycles and measure the effectiveness of the implemented measures is recommended. New traffic light devices to be installed at the intersection must be in accordance with the technical parameters mentioned in "P43 Specification for Traffic Signals" (Waka Kotahi NZ Transport Agency, 2020). Executing maintenance on civil works and maintenance that will consist of repainting the horizontal signs every three months after their implementation is recommended. The handling of the data obtained in the field must be ordered and well-annotated to facilitate the work in the office. Installation of horizontal and vertical signages that are sufficiently visible to road users, considering all harmful elements such as trees, walkways, and posts that limit vision is also recommended. Future studies on the times of traffic lights, depending on the growth rate of the vehicle fleet, in order to avoid future congestion problems, need to be conducted.

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Article

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REVIEW ON PREFABRICATED BUILDING TECHNOLOGY

Rehan Masood and Krishanu Roy

ABSTRACT

In the last three decades, prefabrication and offsite construction have gained wider attention across the globe. There have also been advances in prefabricated building technologies from a product perspective. However, no widely accepted classification system is available to help stakeholders develop their understanding of the prefabrication construction. This study reviews the recent prefabricated building technology classification systems in relation to the product type. Qualitative content analysis was performed to determine the development of the classification systems. Each prefabricated building technology type was reviewed in-depth for differences within classification systems. This study helps academics and practitioners to understand the basic differences amongst prefabricated building technologies, potentially leading to an increase in the uptake of prefabricated construction as stakeholders' knowledge of these technologies improves.

INTRODUCTION

Prefabricated building or construction is also termed offsite construction under the umbrella of modern methods of construction. Prefabrication originates from the 'manufacturing' domain and impacts the industrialisation of the construction process (Gann, 1996). This is an alternative to traditional construction with proven efficiency for productivity, efficiency, quality, safety and sustainability (Moradibistouni et al., 2018; Burgess et al., 2013) in all types of housing (Steinhardt & Manley, 2016; Masood & Lim, 2020). Furthermore, prefabrication has been considered the most suitable solution to improve affordability with an increase in the supply of house building stock (Masood et al., 2016). However, the adoption of prefabrication construction is still limited due to critical challenges, and stakeholders' perceptions is one of the top challenges (Masood et al., 2021). The integration of prefabricated building technologies (PBTs) in the project lifecycle context is more complicated from inception to execution (Pan et al., 2012). However, the early involvement of stakeholders is critical to exploit the benefits of PBTs (David et al., 2017) for residential and non-residential projects. Nevertheless, it is essential to develop a proper understanding of prefabricated construction for efficient and effective application on projects.

There is a plethora of terminologies used to define prefabrication which increases the complexity when developing a clear understanding of PBTs. The alignment of products, processes and supply chains entirely depends on how the client and stakeholder perceive the PBTs (Schoenwitz et al., 2017). The construction industry generally acts in silos and proper integration is not achievable. Similarly, 'innovation' does not have the same meaning for all stakeholders in supply chains. Perceptions about the different PBTs developed from considerations as to which was the best value for money, which in turn depended on the specific context of their use (Agapiou, 2021). Which PBTs are the most efficient depends on various factors and referring to any specific type is not particularly informative (Barlow et al., 2003). However, from a supplier perspective, PBT is viewed as a resource-based definition of the business strategy and portfolios (Goh & Loosemore, 2017).

PBT is linked with product technology, information technology and process technology which inter-relate with the products, people, and business processes (Nadim & Goulding, 2011). This interrelationship varies with the type of the prefabrication by product and material and shapes various business models for several types of houses and the engagement of stakeholders (Pan & Goodier, 2012). A recent review (Masood et al., 2022) on prefabricated house building showed that technology from a supply chain management perspective is also linked with integration, coordination, logistics, commitment, procurement, strategy, network, platform, project management, competency, power, outsourcing, contractors, marketing, sales, and partnership. This shows that PBTs have a substantial impact on the relational and managerial aspects from an organisational (supplier) and project perspective. In another study (Gan et al., 2022), PBT is linked with innovation, hierarchy, structure, development and research. This shapes the knowledge and understanding that PBT is integral in the offsite environment.

Two decades ago, Gibb and Isack (2003) defined the most basic categories of pre-assembly in the PBT context as component (C), non-volumetric (NV), volumetric (V), and modular (M). In project perspective, both C and NV are relatively good in performance, flexibility and innovativeness but V and MB are better in delivery, cost and quality (Jonsson & Rudberg, 2014). However, characterisation of the PBT is essential for its application in the industrialisation of buildings (Yashiro, 2014). PBTs have evolved, but to date, a clear understanding of PBT by stakeholders has still not been achieved, which shapes the knowledge and capability to implement on projects (Tookey, 2021a). This study aims to review the critical aspects of various PBTs to learn how the classification has developed and what the key variations are.

METHODOLOGY

This study uses qualitative content analysis to examine the latest approaches to classify the PBTs and report the key aspects. This review method is applicable in offsite construction literature reviews and provides an opportunity to explore the specific knowledge domain from a multi-perspective (Hu et al., 2019). The selected method is suitable to determine the key trends in defining the PBTs. There is inherent diversification in PBTs discipline-wise as key players in projects have different perceptions about the same PBT. However, the integration of practical knowledge is essential and depends on how well the PBT has been defined, understood and implemented (Pan & Goodier, 2012). To gain recent insight into PBT development and currency of the knowledge, only studies from the last five years were reviewed as no notable research was found to define PBTs. The articles were reviewed for their main approaches to developing the classification of PBTs, and further analysed by the basic types of PBT. The general approach covers the methodology and outcome of each article. Productivity was used as the main criterion to determine the variation amongst the different types of PBTs.

In Table 1, selected research studies, in descending order of publication year, are reported by title, method, and results.

S#	TITLE AND REFERENCE	METHOD	MAIN OUTCOME
1	Nomenclature for offsite construction (Lou et al., 2022)	Mixed research	Criteria for nomenclature
2	Development of an offsite construction typology: A Delphi study (Ginigaddara et al., 2022)	Mixed research	Offsite construction typology
3	Demystifying the concept of offsite manufacturing method – Towards a robust definition and classification (Ayinla et al., 2019)	Literature review	Offsite manufacturing classification by product, process and people
4	BIM in off-site manufacturing for buildings (Abanda et al., 2017)	Literature review	Ontology of offsite manufacturing concepts
5	Production system classification matrix: Matching product standardization and production-system design (Jonsson & Rudberg, 2015)	Case study	Classification Matrix

Table 1: Selected studies on the classification of PBTs.

RESULTS AND DISCUSSION

Studies on PBTs classification

Five key studies, published in the last five years, were selected to determine how the PBTs were classified in academic literature. Jonsson and Rudberg (2015) developed a revised classification matrix based on a case study approach by locating the appropriate PBTs based on the degree of offsite assembly and degree of standardisation. This study classified the PBTs as component manufacture and sub-assembly, prefabrication and sub-assembly, prefabrication and pre-assembly and modular buildings. The critical parameter is the degree of prefabrication and assembly which shapes various PBTs. Abanda et al. (2017) define the ontology of offsite manufacturing concepts developed from sub-assembly component, volumetric, panelised, modular, site-based and hybrid. This ontology was developed to integrate building information modelling in a prefabricated construction stream. This was a pioneer study to investigate the technological integration in buildings. This classification was a step towards systemic integration of PBTs with information technologies. Ayinla et al. (2019) developed an offsite manufacturing system based on products, processes and people. The product-based classification is categorised not only as prefabricated products but also as work sub-sectors, geometry configuration and materials. This study shows the interlinkage of PBTs with other domains. This study provides an extensive classification with coverage of processes such as procurement, production and assembly. This classification system integrates the managerial aspects of PBTs. Ginigaddara et al. (2022) define the typology of the offsite construction. The author categorised two types as non-volumetric and volumetric. In non-volumetric, components, panels and foldable structures were classified. However, in volumetric, there are pods, modules and complete buildings. This study attempts to simplify the PBT classification to avoid jargon. This study combines the strong integration of prefabricated construction with technological advancements with simple categorisation. Lou et al. (2022) investigate the nomenclature for offsite construction using a mixed research approach. Their study defined the criteria for nomenclature as uniqueness, informativeness, conformity, standardisation, relevancy, accuracy, extendibility, and conciseness which originate from physical, digital, construction and information quality. The rule of nomenclature is set on three layers of project code, with high-level component type, high-level component location, low-level component type, and differentiator as additional parameters. This study claims that with this nomenclature a balance between informativeness and conciseness, and also standardisation and extensibility will be achieved. This classification system includes the project dynamics and links with the level of complexity of PBT. All the classification systems address various critical aspects which help to understand the PBT on broader perspective with more clarity on diversifications. However, the classification systems' application in practice is essential which is mainly addressed in the fifth study reviewed (Jonsson & Rudberg, 2015).

Component-based classification (PBT_C)

This PBT demonstrates a low level of prefabrication as it is only focused on component manufacture and sub-assembly happens on site. In a particular building, there are several components which are sub-assembled onsite to shape larger components such as stick-built to wall or truss frames. These are also defined as floor cassette and roof cassette. PBT_C are structural and non-structural by work, and frame system by configuration. There is a problem identifying the specific component and assigning code as there are several components that are the same. However, a proper ordering system is essential from design to installation. This type of system allows high flexibility with pure customisation or tailored customisation which means changes can be made but it restricts the use of materials like steel which is less modifiable than timber. However, the productivity is comparatively low compared to the following PBTs.

Panel-based classification (PBT_P)

This PBT describes non-volumetric products which are prefabricated and sub-assembled partially onsite. PBT_P are many products but a limited number of each are used in housing as there is a clear difference in the offsite work needed considering logistics and cranage requirements. It is comparatively easy to identify the specific panellised unit and assign a code as there are limited numbers. However, a need for proper ordering system is essential from design to installation. When housing is built with panels, it is also called panellised construction. There are two main types of panellised construction – closed and open panellised units or systems. The closed panellised units require less amount of work onsite than the open units. Another term, "foldable structure", like floors, walls, and ceiling, was introduced which demonstrates the stacking and transportation of panellised units rather than "flat-pack." Examples under this classification are cross-laminated timber or structurally insulated panels, and precast concrete panels. PBT_P are building envelopes by work and planar systems by configuration. The PBT_P is suitable for tailored customisation and customised standardisation with high flexibility but low productivity.

Volume-based classification (PBT_V)

This PBT demonstrates volumetric products which are prefabricated and pre-assembled, with the least amount of work onsite which has a more installation focus. PBT_V are a limited number of products but many similar types which potentially cause identification and assigning issues in ordering from design to installation. PBT_V covers mainly bathroom pods used in both residential and non-residential construction. However, volumetric units or modules are also built which are used as part of a building, or the whole building is built with these units. PBT_V are building service by work which is repetitive due to similar design, and box system by configuration. The PBT_V is mainly suitable for customised standardisation with low flexibility but high productivity. This type of standalone PBT demonstrates the prefabricated construction is highly productive if it happens on a large scale.

Modular based classification (PBT_M)

This PBT describes modular products or buildings which are prefabricated, pre-assemble and pre-finished with the very least amount of work on site. PBT_M has one or a limited number of products but very many products of similar types. This type has the least issues in assigning codes for ordering as the whole building is well identified. PBT_M covers mainly whole houses or one stage of residential and non-residential construction. Transportable or relocatable houses are examples of this technology. PBT_P are special structures by work and box systems by configuration. PBT_M are less finished than PBT_V. Hence, there is still some amount of work to be done onsite such as final installation and fixing. Further, there is a risk of damage and a need for long distance transportation if the building is fully complete. The PBT_M is mainly suitable for pure standardisation with low flexibility but high productivity.

Hybrid based classification (PBT_H)

This PBT describes the combination of volumetric and panelised units. This classification comprises both characteristics of the volumetric and panelised systems with relatively the same productivity and flexibility. The PBT_H varies by a number of products and depends on the housing design solution. There is an opportunity to explore the degree of product standardisation within tailored customisation, customised standardisation, and segmented standardisation.

CONCLUSION

This study reports the critical aspects of classifications developed in research of offsite construction for types such as components, panels, volumetric and modular buildings. The classification for PBT has been commonly named from the matrix, (Jonsson & Rudberg, 2015), typology to nomenclature. The research approach in studies on classification has shifted from literature reviews to mixed research which helps to incorporate industry consultation. There has been substantial work to define the basics of the PBT classification but limited focus on the integration of classification systems with advanced technologies like Building 4.0. Work has also focussed on defining high and low prefabricated components rather than conventional types of PBTs. The PBT classification system has not reached maturity as there are still provisions to revise to align them with the advancements in PBTs. Further investigation of aspects which potentially impact the classification system will enhance the applicability and contextual relevancy. Recent classifications attempt to simplify the PBTs to clarify the technology system to better understand the prefabricated product application. There is less provision for hybrid prefabricated construction in the current classification systems. This study investigated the generalisation of the classification system and found that there is a lack of integration from theory and practice perspectives. Nonetheless, more emphasis is now on the practicability of the classification system, which will help the industry and academia align perceptions of the PBT.

In all PBT classifications, by definition, prefabrication and assembly are dominant factors. Further, the frequency and similarity of by-products is also considered a significant differentiator. Possible usability, work assignment and configuration of each PBT also creates a clear demarcation. Nonetheless, the comparison of productivity and flexibility is still valid for the PBT classification system. Each PBT has potential to enhance the project's performance but several aspects should be considered. There is a need to address the classification system to cover transportation and on-site assembly which also share the key performance criteria (Grenzfurtner et al., 2022).

In a recent industry survey (Tookey, 2021b), a decline has been observed in the pod and modular construction in New Zealand, which suggests serious efforts should be taken by the government, academia and industry in promoting the uptake of PBTs. Government should consider the inherent diversification of the PBT system for developing housing policies, such as which PBT is suitable for medium-density housing. Understanding the classification system is helpful in the development of skills and qualifications for offsite construction workforce. The robust classification system helps practitioners decide which specific PBT system to implement on projects. Nonetheless, this study gives an overview of the classification for PBTs reported in the literature and what are the key dynamics and development trends towards a better understanding of prefabricated construction.

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IN-DEMAND JOB SKILLS MONITOR

David Rozado, Francisco Rosas, Yoseob Shim
and Michael Holtz

ABSTRACT

A competitive economy needs a tertiary education system capable of equipping present and future members of the workforce with the skills needed by industry. Currently, the task of identifying what skills to teach within tertiary degree programmes is mostly carried out by regulatory agencies and educators who choose, to the best of their knowledge, the components to embed in degree courses based on their expertise and subjective intuition about what skills will better prepare learners for the job market. Could this model be suboptimal? A number of biases such as convenience sampling, motivated reasoning, group thinking, or incomplete information could creep in while academics and regulators engage in the curriculum design of tertiary education courses. We propose a complementary automated tool that quantifies the skills employers demand by monitoring and analysing the content of job advertisements within a given geographic region and aggregating them by job type. Such a system can empower tertiary education institutions to fine-tune the content of their courses accurately to meet actual, rather than guessed, industry demands for job skills.

INTRODUCTION

In a competitive job market, potential employers demand specific skills and prospective employees offer to supply that demand with their talent and abilities. In an efficient job market, the supply elastically adjusts to meet changing demand. This process is mutually beneficial for employers, employees and the wider economy. A mismatch between prospective employees' skills and industry demands can lead to job seekers' frustration (Altmann et al., 2018), lack of industry competitiveness (Middleton et al., 1993), decreases in productivity (Vandeplas & Thum-Thysen, 2019), and inefficient public spending in education and unemployment benefits (Cappelli, 1995). Thus, in order to thrive, a competitive economy needs a workforce equipped with the skills demanded by employers.

In modern societies, the task of equipping present and future members of the workforce with the skills needed for their career falls largely under the responsibility of tertiary education institutions: universities, polytechnics, institutes of technologies and other tertiary education providers (Salmi, 2003). Regulatory agencies and staff employed by tertiary education institutions often use their subject expertise and intuition to decide the content and skills to be taught/develop within degree programs. We contend that a number of cognitive biases such as motivated reasoning, convenience sampling, group-thinking or incomplete information can creep-in during this process (Vandeplas & Thum-Thysen, 2019). Furthermore, academics and regulators are often disconnected professionally from industry, with the majority of lecturers and professors spending most of their non-teaching time in research and departmental administration tasks that are often disconnected from industrial realities. Thus, we suggest a complementary data-driven tool to help tertiary education institutions determine the skills that are in-demand by industry.

The present work was motivated by previous findings suggesting a growing gap in the New Zealand job market between demands from employers for certain skills and an under-supply of qualified potential employees (NZTech, 2021). This mismatch could suggest under-investment in developing the existing New Zealand workforce and/or lack of coordination between industry and tertiary education providers. The dramatic skills shortages in some strategic industries (NZTech, 2021) drive a heavy reliance on immigration to supply unmet demand and create a national vulnerability in the receptor country and a brain drain in the source country.

Our proposal consists of an automated tool that monitors job advertisements within a geographic region (that is, city, state, country) and quantifies the prevalence of technical and professional skills for different professions in those job advertisements. The data is then aggregated by job type and conveniently visualised to provide an overview of the most demanded skills for a given profession. We contend that our tool could help tertiary education providers to fine-tune the content of their programmes to better meet current industry demands. Such a data-driven, implicit coordination between industry demands and the content of academic degrees could help mitigate professional skills gaps in the job market (APAC, 2021).

It is important to emphasise that our proposed system should not be considered a substitute for human judgment. We instead consider it a complementary tool that augments human expertise and decision-making by leveraging a quantitative overview of the skills demanded in a particular job market. We can think of several pedagogical reasons for which an educator might justifiably choose to prioritise the teaching of a tool or skill over another even when the former is less demanded by industry than the later. Thus, the ultimate curriculum design choices should still be made by regulatory bodies and educators who can integrate our quantitative data analytics with their contextually-aware expertise.

IN-DEMAND JOB SKILLS MONITOR

We briefly describe next the web application prototype we have created for illustration purposes. Our application quantifies the skills demanded by New Zealand industry by automatically monitoring job announcements in popular NZ employment advertisement sites and aggregating mentions of required skills by job type.

Conceptual overview

The *In-Demand Job Skills Monitor* web application consists of an online interface that allows a user to choose from a group of professions, a role or job title of interest in order to retrieve visualisations that quantify the technical and professional skills that are currently in-demand for such a role in the New Zealand job market.

The job types are classified within the application into several major categories such as *Information Technology* or *Medical & Health*. The major categories are, in turn, divided into common subcategories such as *Developers* or *System Administrators* and *Nursing* or *General Practitioners* respectively.

The application is comprised of two parts, a 'Backend' to store, process and serve data and a 'Frontend' which retrieves this data and transforms it into a visual representation.

Backend

The setup of the system consists of a Linux virtual machine on Google Cloud which holds a containerised Postgres database using Docker, an automated Python web scraping script and a FastApi GraphQL API server to expose the data to the outside world. An overview of the Backend component of the application is shown in Figure 1.

The job listings are scraped from popular job advertisement services, parsed and saved into the database. In case of dynamic content, the automation tool, Playwright, is used.

From the scraped information, a sample of job descriptions for a given job category is then used to manually extract job type-specific vocabulary comprising a set of terms for what the employers demand for this job type. This process allows us to define new classifications which will be used for data labelling using the annotation tool UBIAI and regular expressions. As a result, around 120 job descriptions are manually labelled and then used to train and fine-tune a ROBERTA transformer model for the task of Name Entity Recognition.

Once we have a trained language model, we use it to label the rest of the job descriptions for the job category in question. Then we count the number of mentions for each term in a category in all the job descriptions.

Lastly, we create a GraphQL API to query all the processed data in the database and serve it using Ariadne and FastApi to make it available to the Frontend.

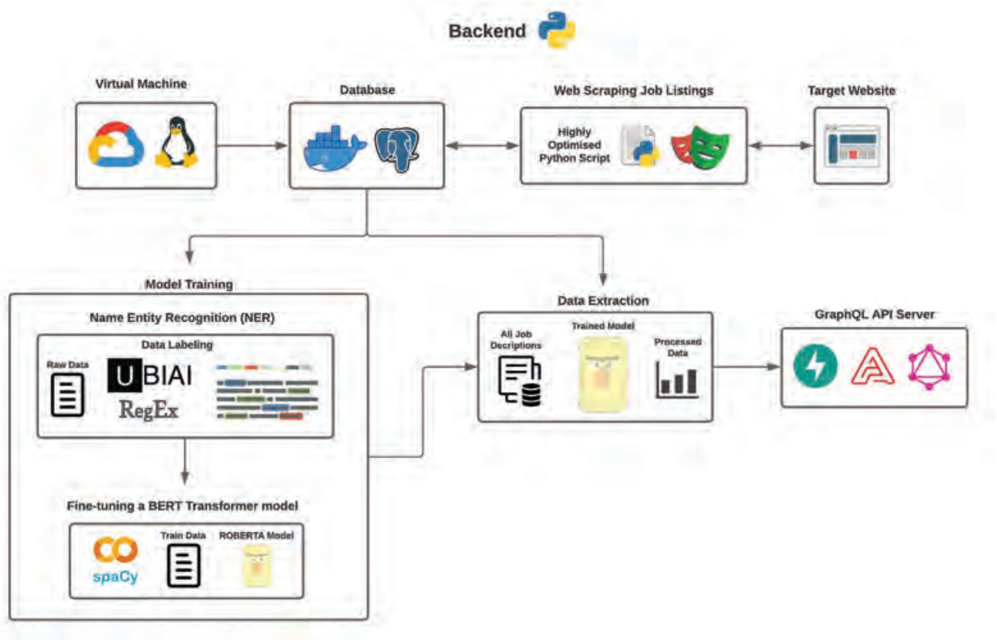

Figure 1. Conceptual overview of the Backend side of the In-Demand Job Skills Monitor App.

Frontend

A Static Site is generated with a NextJS application based on the Javascript framework React, which provides server-side functionality. This application is styled using the Material UI component library for React which abides by Google's design principles. An overview of the Frontend component of the application is shown in Figure 2.

This application retrieves the data using Apollo Client, a third-party library that provides an easy-to-use set of tools to fetch information from GraphQL APIs. Once all the necessary data is fetched, we use the libraries Mapbox and ApexCharts to help us visualise the information in the form of maps and charts, respectively. We apply animations using the React library Framer Motion and then proceed to deploy this application to Vercel, a platform to host web applications. Every time new data is scraped on the Backend, we redeploy the site to provide up-to-date information.

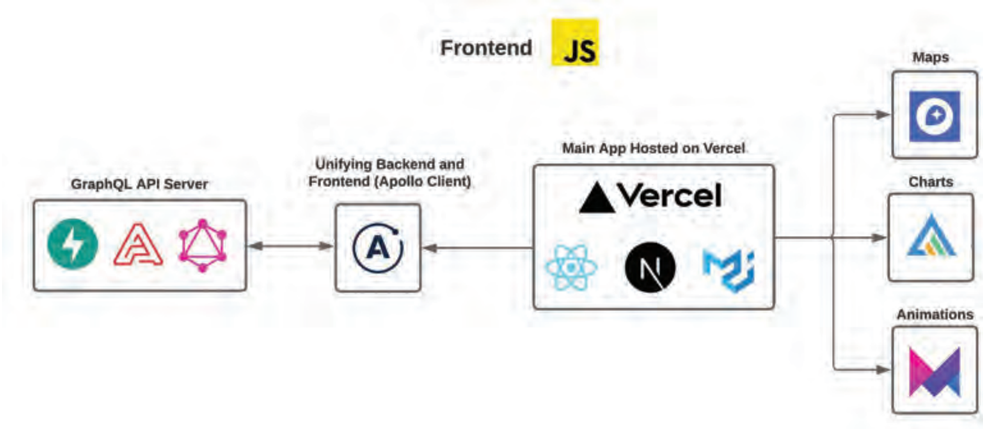

Figure 2. Conceptual overview of the Frontend side of the In-Demand Job Skills Monitor App.

Hardcoded skills vs machine estimated skills

Analysing natural language text requires efficient mechanisms to deal with ambiguity. When seeking information in text corpora, it is often helpful to consider 'context' and be cognisant that simple string matching through regular expressions is often insufficient for information retrieval purposes. That is, there are often an enormous amount of possible text configurations to express ideas such as the set of skills required for a job type. Machine learning-based natural language models fine-tuned for fuzzy information retrieval can help to identify such instances. This is often achieved by language models that represent the semantics/syntactic features and relationships between terms as a structured numerical vector that can be easily queried for fuzzy matching.

To illustrate this idea, let us say we want to match jobs that require *communication skills*. A simple template matching query system searching for the bigram *communication skills* would miss job listings that talk about *verbal skills* or *being good with words* unless such expressions are included explicitly as a set of synonyms for *communication skills*. Such an approach has obvious limitations for scaling. In vector space however, all semantically similar terms to *communication skills* would be located in adjacent regions in vector space by virtue of their semantic similarity. Thereby, a machine learning-powered language model is able to detect job types that require communication skills even if they all use different terms to express that concept.

Prototype

Figure 3 shows an illustrative output of the system for the query *software developer*. The figure clearly shows how our prototype application has captured the frameworks, programming languages, collaborative tools, database management systems and other technical tools that are most in demand by the New Zealand IT industry at the time of the query (November 2021) for the *software developer* profession. Our system has also captured the soft or professional skills that are often requested by potential employers for this role as well as the companies offering the most jobs in this category, the average salary and a geographic distribution of this job type around the country.

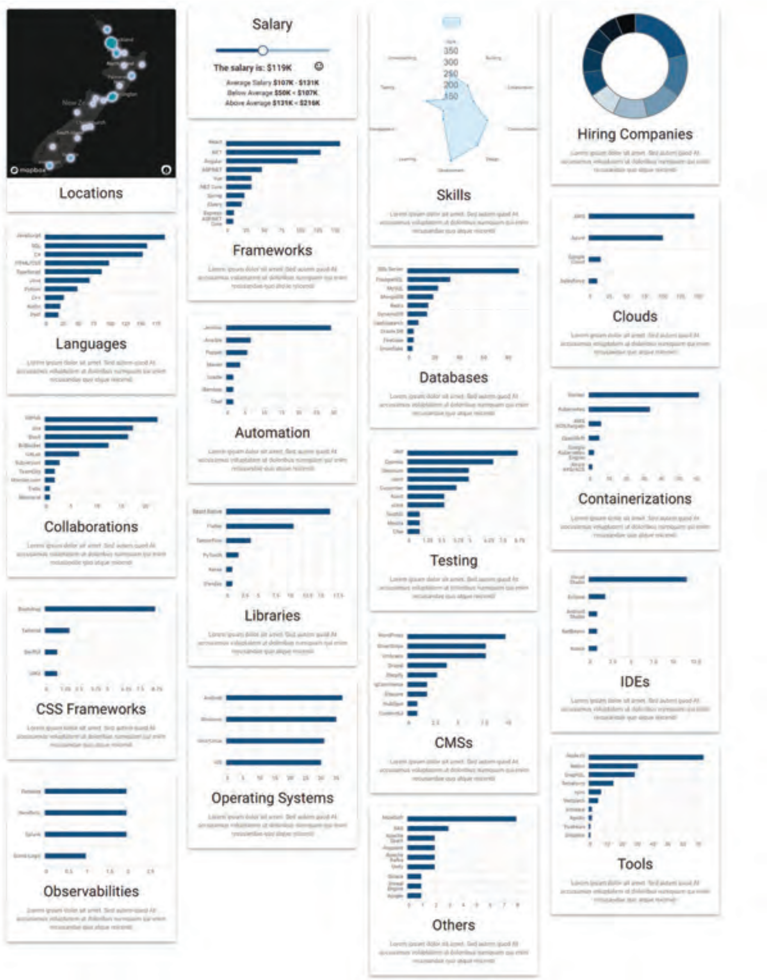

Figure 3. Visualisation of skills demanded by New Zealand employers for the role of 'software developer' as estimated from job ads in popular job advertisement sites.

CONCLUSION

This work has argued that the process of choosing content to be embedded in the educational programmes offered by tertiary education providers is often carried out in an ad-hoc manner that often leverages the expertise of regulators and educators to estimate the skills needed within a geographical job market. While this approach can be informative and valuable, it can also be limited by intrinsic cognitive biases and incompleteness of information available to academic staff and regulatory bodies. We propose a complementary system that estimates technical and professional skills demanded by industry within a given geographic region by monitoring job advertisements and quantifying the degree to which different technical and professional skills are demanded by job type. Our proposed system can help fine-tune the academic content delivered by educational institutions to actual, rather than guessed, skills demanded by industry. We hope our proposal and existing prototype can spark future investigations into how tertiary education providers can better fulfil industry demands for a skilled labour force to ensure the future employability of their students.

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Article

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DENOISING ACOUSTIC EMISSION SIGNAL USING EMPIRICAL MODE DECOMPOSITION METHOD

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ABSTRACT

Acoustic emission (AE) plays an important role in Structural Health Monitoring (SHM) applications by providing the early-stage damage assessment of composite materials. However, the collection of AE signals is challenging due to complex noise arising from the mechanical equipment, temperature, vibration, friction as well as external and internal environments of the structure. In order to overcome this challenge, even though many denoising methods have been introduced to acquire the denoised AE signals, there is still a lack of effectiveness in denoising without degrading the originality of the AE signals. Therefore, this paper adopts an efficient denoising method named Empirical Mode Decomposition (EMD) to remove most of the noises of the acquired AE signals by keeping its original properties. The adopted method is initially utilised on synthetic datasets which are randomly generated inducing various levels of Gaussian white noise. The obtained results are then compared to the original properties of the randomly generated clean dataset to evaluate the effectiveness of the EMD method. Experiments have been carried out to acquire the AE signals added with friction and vibration noises and then the EMD method is applied to them to eliminate the noises. The performance of the EMD method has been evaluated based on different performance metrics. Results show that the EMD method effectively removes most of the noises without disrupting original properties of the AE signals.

INTRODUCTION

Acoustic emission (AE) has recently received significant interest in the area of structural health monitoring, especially for corrosion and crack detection, damage, and leakage monitoring. Acoustic emission is a transitory elastic wave phenomena generated by the change of some outer conditions such as temperature, stress, and so on (Joseph & Giurgiutiu, 2020). Acoustic emission signals generate a variety of monitoring characteristics, including amplitude, rising time, energy, and hit count, that can be utilised to inspect existing micro-cracks in concrete. These parameters are also utilised for determining the location of the micro-crack. Due to the fact that the AE signal is produced by a variety of other causes, including temperature, friction, and vibration, the collected AE signal has weak characteristics and overlapping frequency bands when compared to the complex noise background (Kharrat et al., 2016). To enable online structural damage identification, it is important to obtain a clear AE signal from a damage source against a noise background. Thus, noise reduction of AE signals is necessary in SHM applications when assessing the welded structure's damage.

Numerous denoising techniques have been introduced and implemented in the literature as a pre-processing tool outside of the data collecting system (Liu et al., 2018; Khamedi et al., 2019; He et al., 2020; Ji et al., 2018). Fast Fourier Transform (FFT) is a widely used denoising algorithm that is typically included into commercial AE data collecting systems. The FFT converts a time-domain signal to a time-frequency domain signal in order to obtain the signal's frequency information and suppress non-essential aspects. While FFT is an excellent method for denoising, it produces a signal with a poor resolution and is incapable of doing time and frequency domain analysis concurrently (Liu et al., 2018). Additionally, FFT is inefficient when dealing with non-stationary and transient inputs (Liu et al., 2018). In comparison, wavelet transform (WT) is another renowned denoising technique which is based on the linear transformation. In WT, the basic functions are modified by following the scaling function of a "mother wavelet" (Satour et al., 2014). Discrete Wavelet Transform (DWT) (Ramos et al., 2017), Wavelet Packet Transform (WPT) (Khamedi et al., 2019) and Stationary Wavelet Transform (SWT) (Nason & Silverman, 1995) are some of the most utilised denoising methods in the WT family that eliminate the various types of the noise of AE signal coming from the damage portions of the weld materials. The expanded DWT models such as WPT and SWT provide the details resolution for the AE signal. An eye-catching noise reduction has been gained for the non-stationary AE signals through its multi-resolution properties (He et al., 2020). However, the obtained AE signal is sensitive to the nature of the application, which may include random noise. Several sources of noise are typically added to the AE signals during collecting, including ambient and internal noise, mechanical equipment, vibration, friction, and white noise. These noises may serve as a misleading means of deriving required knowledge from the signals. Thus, these noises of the AE signal should be suppressed before performing the knowledge-discovery methods. We use the Empirical Mode Decomposition (EMD) approach in this research to decompose the AE signal into multiple components based on the signal's frequency information and magnitude. To achieve gain in denoising, unwanted components are removed using Euclidean distance calculations and then the transformed signal is reconstructed to provide the denoised AE signal.

The remainder of this article is structured as follows: The materials and methods section discusses the data acquisition system and the denoising method used, as well as many evaluation criteria. The following section analyses the results and discussions. The article ends with the conclusion.

MATERIALS AND METHODS

This section discusses different characteristics along with some parameters of the test specimens. The AE data acquisition system's experimental details are provided.

Acoustic emission signal acquisition

Continuous AE signals were recorded during the hydrogen evolution process. The signals were analysed using a four-channels data collection system equipped with an integrated low-noise preamplifier. In this study, a piezoelectric sensor with an acquisition threshold set to a specific decibel level was used. The sensors and coupling agent are attached to the specimen and fixed with a magnetic holder in a four-clock position (12, 3, 6, 9 o'clock) on a carbon-steel pipe. Physical Acoustics Corporation supplies the entire system, including the AE sensors (USA). Prior to the tensile test, the signal acquisition system was calibrated using the pencil lead break technique. Numerous acquisition software parameters, such as hit definition time (HDT), peak definition time (PDT), and hit lockout time (HLT), have been given in Table 1. Setting these values is dependent on the material's type and nature, positioning of the active region and the AE sensors. In our data collecting system, each AE strike generates 1024 discrete data points. AEwin software (Express-8 and version V5.92) manufactured by MISTRAS was used to capture AE signals.

PARAMETER	VALUE
Hit definition time (HDT)	2000 μs
Peak definition time (PDT)	1000 μs
Hit lockout value (HLT)	500 μs
Threshold value	40 dB
Sample rate	1 μs per sample

Table 1. Acoustic emission parameters.

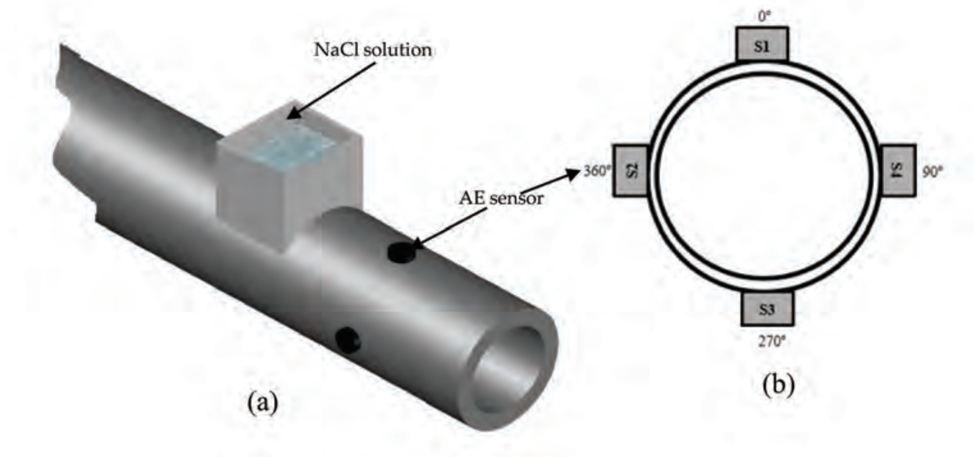

Figure 1. Schematic diagram for (a) cathodic hydrogen charging setup and (b) cross section pipe with location of sensors.

Denoising signal based on EMD

Huang (2014) created Empirical Mode Decomposition (EMD), an adaptive time-frequency decomposition method that makes use of the Hilbert–Huang Transform (HHT) for time-frequency analysis. The EMD method's primary characteristic is that it converts a given signal $x(t)$ into a total of oscillatory functions dubbed the Intrinsic Mode Function (IMF). The shifting process is carried out to obtain the IMF. The EMD technique requires that an IMF should satisfy two conditions: firstly, the sum of the maxima and minima, and the zero-crossing number must be 1; secondly, the local average must be 0. The signal is split into numerous IMFs based on its time scale properties. EMD decomposes the given original signal $x(t)$ as shown in Equation 1:

$$x(t)=\sum_{i=1}^{n} IMF_i(t)+rn(t) \tag{1}$$

where $IMF_i(t)$ and $rn(t)$ denote the IMF components' sequence and residual component, respectively. The first IMF shows an impact of high frequency, while the impact of subsequent IMFs declines proportionately until a non-smooth signal gained. By choosing the best IMFs which has residual components and high frequency, the signal may be reconstructed. The true IMFs are determined by determining the Euclidean distance, d, between the first IMF and the remaining IMF components, as shown in Equation 2.

$$d=\sqrt{\sum_{i=1}^{n}\left|x_i-y_i\right|^2} \tag{2}$$

where x_i and y_i are the i^{th} respective samples of the observed signal and the extracted IMF. The redundant IMFs have shape and frequency content different than those of the original signal. So, the value of d for redundant IMFs will be maximal. When IMFs are not appropriate, the value of d presents a maximum value.

The EMD method's efficacy in denoising signals is evaluated using a variety of performance indicators, including Signal-to-Noise Ratio (SNR), Root Mean Square Error (RMSE), and cross-correlation. The explanations with the mathematical equations are presented as follows:

SNR: It is a comparison between the levels of signal noise in original signal $x(l)$ and desired denoised signal $\bar{x}(l)$. SNR is the ratio of original mean signal power and mean noise power, and it is represented by the following equations.

$$SNR = 10\log_{10}\left[\frac{\sum_{l=1}^{n} x^2(l)}{\sum_{l}^{n}\left[\bar{x}(l) - x(l)\right]^2}\right] \tag{3}$$

RMSE: It is applied to calculate the error of reconstruction generally after denoising a signal. This may be estimated by taking the root of the ratio between the total number of samples in the signal and the mean-square difference between the original signal $x(l)$ and the denoised signal $\bar{x}(l)$. The following definition applies to the RMSE:

$$RMSE = \sqrt{\frac{\sum_{l=1}^{n}\left[x(l) - \bar{x}(l)\right]^2}{n}} \tag{4}$$

Cross-Correlation ($xcorr$): It is used to determine the similarity between two discrete time sequences. If the cross-correlation value $xcorr$ is near to 1, the cleaned signal and the signal with noise have a high degree of similarity. The cross-correlation can be stated in the following way:

$$xcorr = \left[\frac{E\left(\bar{x}(n) - \mu_{\bar{x}}\right)\left(x(n) - \mu_x\right)}{\delta_{\bar{x}} - \delta_x}\right] \tag{5}$$

where $\mu_{\bar{x}}$ and μ_x represent the mean values of the denoised signal $\bar{x}(n)$ and the noisy signal $x(n)$, respectively, and $\delta_{\bar{x}}$ and δ_x signify the two signals' corresponding standard deviations. The statistical expectation or mean function is denoted by the operator $E()$.

RESULTS AND DISCUSSION

This section describes the simulation environment, datasets, and parameters used in the experimentation.

Simulation setup and datasets

Experimental AE data are gathered during hydrogen evolution and artificially generated friction and vibration noises on the carbon steel pipeline (May et al., 2020). Additionally, the synthetic datasets are created at random using varying degrees of Gaussian white noise. Following that, the adopted EMD approach is applied to both types of datasets to evaluate the denoising performance of our denoising method. In AE datasets, there is just one type of measurement (AE signal amplitude in mV), which is captured as waveforms at each microsecond sampling interval and consists of 1024 measurements. The EMD approach was applied to the first 1000 waveforms of a single AE sensor, resulting in a total of 1,024,000 discrete time points being measured. In comparison, the synthetic datasets are generated algorithmically and include signal-to-noise ratios (SNR) of 5 dB, 10 dB, 15 dB, 20 dB, and 25 dB. The datasets are one second in length and sampled at a rate of one millisecond. Additionally, simulations on the datasets are run in the MATLAB environment to evaluate the EMD denoising method's performance.

Denoising of synthetic datasets using Gaussian white noise in accordance with EMD

The algorithmically created sinusoidal clean signal is displayed in Figure 2, along with artificially inserted Gaussian white noise signals at various levels of SNR, including 5 dB, 10 dB, 15 dB, 20 dB, and 25 dB. The vertical axis of the graphic represents the signal's amplitude, while the horizontal axis represents time. The synthetic clean signal is utilised as a reference signal, and the EMD-based denoising approach is applied to randomly produced noisy signals to evaluate its performance in terms of denoising accuracy without affecting the reference signal's essential features. In Figure 3, we compare simulated clean signals to EMD-based denoised signals in order to measure the EMD method's efficacy in removing various amounts of Gaussian white noise. Additionally, the performance of the EMD approach in denoising severe level noisy signals is evaluated using three criteria (SNR, root mean square error, and cross-correlation) and the resulting results are compared to those of noisy signals. As illustrated in Figure 3, even if there is a modest effect on the amplitude of the de-noised signals only in the case of extremely noisy signals, the remaining attributes of the de-noised signals are nearly identical to those of the clean signal. Additionally, the SNR and cross-correlation values obtained for EMD-based de-noised signals are higher with a smaller reconstruction error than the values obtained for noisy signals. Table 2 compares the performance of the clean signal,

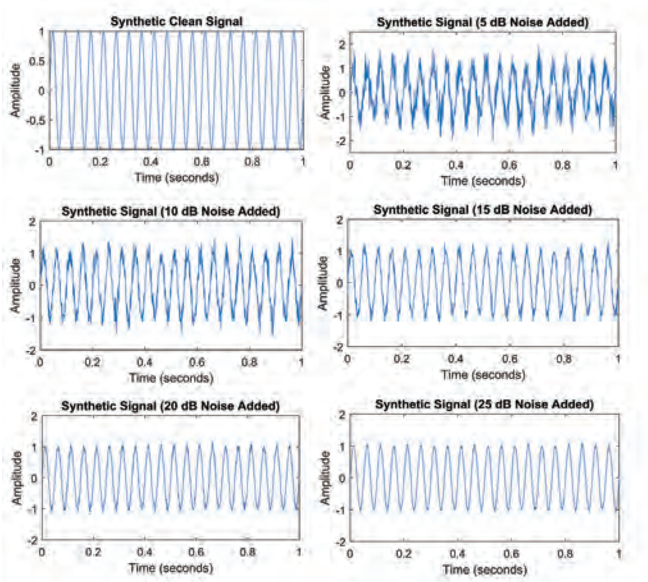

Figure 2. Synthetic clean signal and the signals with the addition of several degrees of Gaussian white noise.

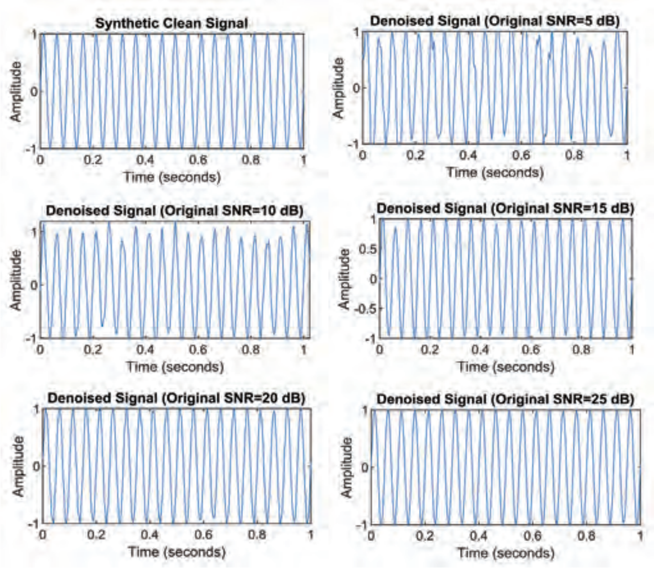

Figure 3. Comparison between synthetic clean signal and the EMD-based denoised signals.

the properties of various levels of noisy signals, and the properties of EMD-based de-noised signals. According to Table 2, all attributes of the clean signal except the "Max Peak Frequency" feature are altered by the various degrees of Gaussian white noise. However, the EMD denoising approach effectively removes multiple levels of noise, and the denoised signals have essentially identical qualities to the clean signal. Thus, it can be asserted that EMD is an effective method for denoising extremely noisy signals without impairing the signal's core features.

Denoising of frictional noisy AE signal using EMD method

By rubbing a steel plate against the same test specimen and adjusting the other settings as indicated in the Materials and Methods section the frictional noisy AE signal was captured. Then, using the proposed EMD approach, frictional noise is removed from the recorded AE signal, and the noise reduction performance is evaluated. The frictional noisy AE signal, the EMD-based de-noised signal, and estimated noise are all depicted in Figure 4. The de-noised EMD signal demonstrates how the EMD approach effectively lowers frictional noise while retaining critical AE information.

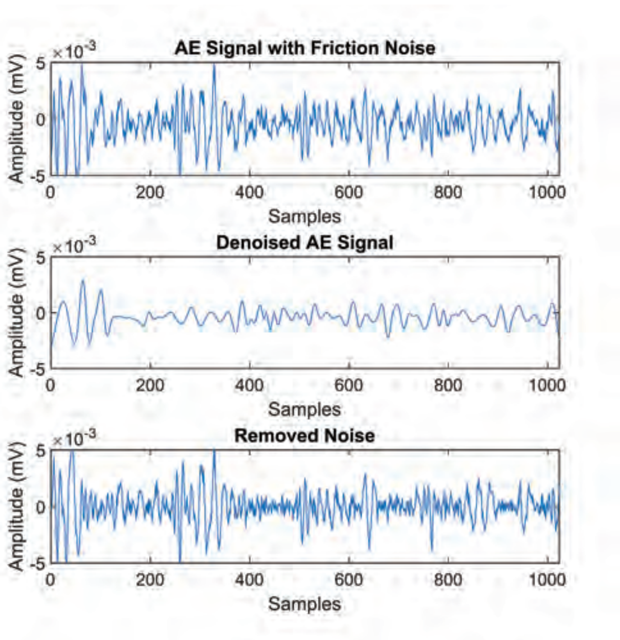

Figure 4. Comparison among frictional noisy AE signal, the AE signal after EMD-based denoising and estimated noise.

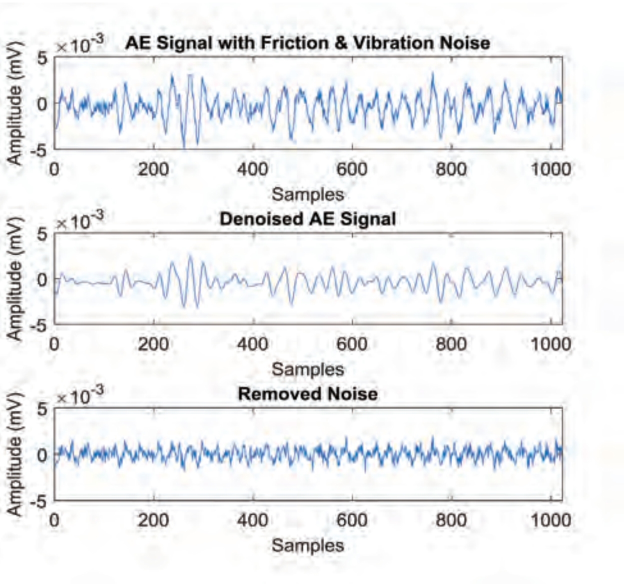

Figure 5. Comparison among frictional and vibrational noisy AE signal, the signal after EMD-based denoising and estimated noise.

Denoising of frictional and vibrational noisy AE signal using EMD method

As mentioned previously, frictional and vibrational noise were determined by rubbing and pounding on the same object during the experiment. To remove both noises from the collected noisy AE signal, the EMD denoising method is used and the denoising performance is compared to the original noisy AE signal. The frictional and vibrational noisy AE signals, the EMD-based de-noised signal, and predicted noise are all shown in Figure 5. The de-noised EMD signal in Figure 5 demonstrates that the EMD approach effectively eliminates both noise and critical AE information. Thus, the EMD denoising method can be used to decrease not only frictional noise, but also vibrational noise in AE data obtained from SHM applications.

Properties	**Clean Signal**	**25 dB**	**20 dB**	**15 dB**	**10 dB**	**5 dB**
Number of Peaks	21.00	209.00	209.00	209.00	273.00	338.00
Max Peak Frequency (Hz)	19.53	19.53	19.53	19.53	19.53	19.53
Mean Frequency (Hz)	19.80	20.53	22.01	26.58	41.27	71.47
Angular Frequency (Hz)	125.54	1291.41	1291.41	1690.43	1970.83	2082.04
RMS Bandwidth (kHz)	0.87	60.24	60.24	110.20	107.47	101.97
Mean Frequency Power (dB)	-6.01	-5.97	-5.86	-5.80	-5.30	-4.26
RMSE	0.00	0.04	0.07	0.12	0.23	0.38
SNR (dBc)		24.49	20.91	15.66	9.29	6.04
xcorr (%)	100.00	99.84	99.52	98.48	95.17	87.76
EMD-Based denoised signals						
Number of Peaks	21.00	21.00	21.00	21.00	22.00	29.00
Max Peak Frequency (Hz)	19.53	19.53	19.53	19.53	19.53	19.53
Mean Frequency (Hz)	19.80	19.88	20.01	19.94	20.02	20.39
Angular Frequency (Hz)	125.54	125.92	132.21	125.79	131.82	176.11
RMS Bandwidth (kHz)	0.87	0.87	0.84	0.84	0.86	1.53
Mean Power (dB)	-6.01	-5.96	-6.12	-6.19	-6.01	-5.21
RMSE	0.00	0.03	0.04	0.06	0.10	0.17
SNR (dB)		32.54	26.52	23.06	19.76	16.98
xcorr (%)	100.00	99.94	99.82	99.68	99.09	97.34

Table 2. Comparison among the properties of synthetic clean signal, different degrees of noisy signals and the EMD-based denoised signals.

Hilbert frequency spectrum of the noisy AE signals and EMD-based denoised signals

According to Wu et al. (2015), the usual frequency spectrum of the generated AE signal is focused between 20 and 80 kHz during hydrogen evolution activity. This frequency range is mostly determined by bubble formation during hydrogen evolution activity and the level of induced potential. The Hilbert frequency spectrum of the original frictional and vibrational noisy AE signals is compared to the frequency spectrum of the de-noised AE signals generated using EMD in Figure 6. As seen in the plot, the frictional and vibrational noisy signals produce primarily overlapping frequency bands and have a negligible effect on the magnitude. The EMD method eliminates superfluous frequency components while retaining the useful frequency spectrum, as seen in Figure 6 by the EMD-based denoised Hilbert spectrum.

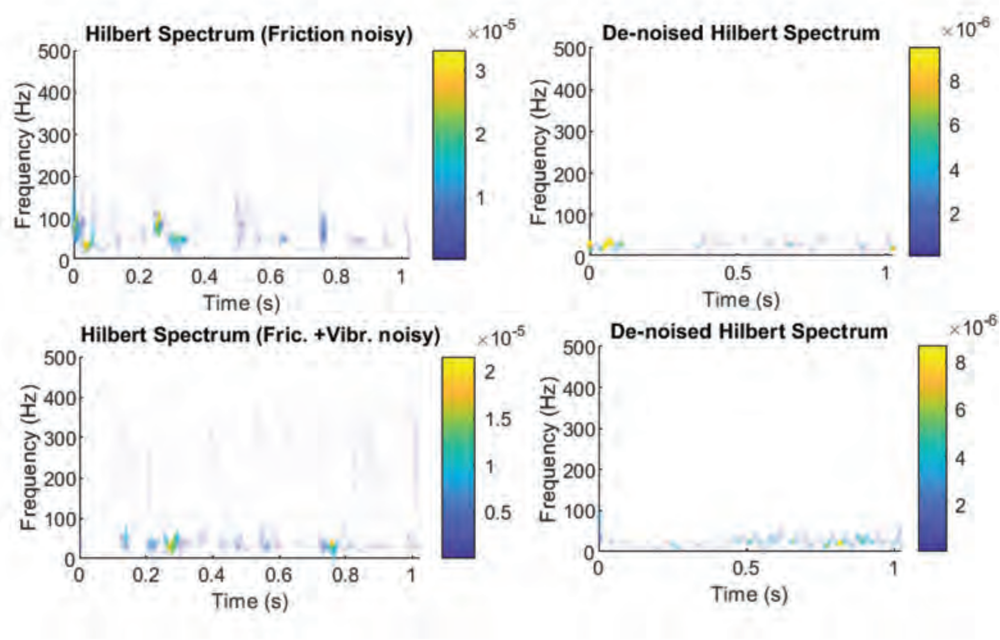

Figure. 6. Comparison among Hilbert spectrum of the Original noisy AE signals and EMD-based denoised AE signals.

CONCLUSION

According to the findings and analyses of this work, the denoising method is critical in a variety of applications in SHM for the gathering of cleaned AE signals to increase the effectiveness of early-stage damage assessments. By minimising the reconstruction error, the adopted EMD approach significantly reduces the noise in AE signals gathered during tests, making it effective for extremely noisy AE signals recovered from a variety of monitoring applications in SHM. The simulation results produced using the EMD method demonstrate that the properties of the EMD-based de-noised signal are nearly identical to those of the original clean signal. Additionally, the outcomes of evaluation criteria such as SNR, RMSE, and cross-correlation are improved when using de-noised signals as opposed to noisy signals. The EMD denoising technique may be used to effectively capture AE clean signals during SHM inspection in real-world situations. However, preparatory study should be undertaken to determine the acquisition parameters based on the wavelength, threshold value, the accuracy of the AE sensor, and the wave velocity for a particular structure. Appropriate parameter selection can aid in the removal of reflected waves and other unwanted noise. This study can be expanded to include real-world SHM applications for the gathering of cleaned AE signals to evaluate the EMD method's denoising performance.

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Article

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A PILE OF STICKS IN DRYAD FASHION: INTRODUCING THE COMPACT UPRIGHT WEAVING LOOM (CUWL)

Pam McKinlay

ABSTRACT

This article follows the iterative development of a bespoke upright hand loom, as a process of experimentation and modification to create a weaving instrument to fulfil personal requirements for new weaving projects. In the absence of any written research on loom design and loom mechanics for this particular style of loom, the studio methodology was to make and evaluate by trial and error, picking up ideas from photographs of looms in weaving blogs and looking at the sample weaves produced on each successive loom design to work out where the next change needed to occur, be it to create a stable tension, roll on, shed changing or thread packing. As a result, this article uses an autoethnographic approach in writing up resulting workshop and studio research.

INTRODUCTION

Weaving is an ancient technology, and one wonders what innovation one could possibly bring to the table after thousands of years of refinement. Here we introduce an iterative loom design project that has been ongoing for several years to answer my personal 'perfect-loom' challenge. For those unfamiliar with the technique, we will introduce some basic weaving vocabulary before a more in-depth look at the vagaries of tapestry weaving. The solutions were arrived at during two phases of development with an intermediary period of follow-up research online after Phase 1 to consolidate what we had learned in the workshop and to plan possible options before proceeding with Phase 2.

> Weaving is one of the oldest surviving practices in the world, with its history firmly rooted in the Neolithic period when the creation of woven textiles exploded, with most households producing their own cloth. Since then, weaving has influenced history and culture around the planet, becoming an indispensable skill connected to family traditions, farmed fibres and local production – spanning to modern times when the loom became mechanised during the Industrial Revolution … The loom is of course a tool for weaving, but it also becomes an object of veneration and reflection, a self-sufficient work of art. (New York Textile Month, 2022)

I began my weaving journey with the view of following in my family's footsteps of weaving and becoming a tapestry weaver (McKinlay, 2022). My grandfather built a hefty floor loom at home and worked in the Kaiapoi woollen mills after emigrating from Bradford in Yorkshire, where he had worked in the mills since he was a 10-year-old boy (not the legacy I was pursuing). On my great-grandmother's side of the family, there were stories handed down of our ancestors as renowned tapestry weavers from Flanders who had worked on the Hampton Court tapestries and in Welsh monasteries before that (Hart, 2017). Thread is in my blood. I began learning shaft-weaving from Master weaver Christine Keller at Dunedin's LoomRoom at its inception in 2014. In 2021, I was fortunate to get a space in Master tapestry-weaver Marilynn-Rea Menzies's workshop class when she made a visit to Ōtepoti Dunedin (Fox, 2021). Tapestry weaving at one level appears to be the most seductively simple of weaving styles:

> There are many kinds of looms that can be used to weave tapestry. Virtually any structure that can hold a set of warp threads in order and taut will work in some fashion. Kids weave them on cardboard boxes all the time. (Camezoff, 2015)

Weaving on a loom involves the interlacing of two sets of threads at right angles, with the loom being a device to keep one set of inelastic threads taut or stretched under tension (warp) while the moving threads are passed over and under. The basics can be learnt by the youngest of nimble fingers but attaining proficiency in the art is another matter, requiring long years and thousands of hours of practice and technique. At the other end of the spectrum are master weavers working in the fields of production, fashion, homewares, upholstery, flooring rugs, corporate commissions, and tapestry.

TAPESTRY WEAVING

The definition of the word tapestry today describes a range of textiles, including needlepoint and certain woven fabrics, but historically and technically it designates a textile woven by hand on a loom. The design might be figurative or abstract, but it is 'weft-faced' in its making, which means the finished weaving hides all the warp threads; this in contrast to shaft weaving where the revelation or hiding of a mix of warp and wefts make up the final pattern. Looms generally fall into two categories by the way they are warped, either high-warp (standing vertical) where the warp runs perpendicular to the floor or low-warp in which the warp runs parallel to the floor (or in a horizontal plane) as in the Flying8 loom shown in Figure 1. "High-warp looms are the looms most people think of when you say tapestry," comments Rebecca Camezoff (2015), "The warp runs mostly perpendicular to the floor and the work sits in front of the weaver much like it would when hung on a wall."

As an intermediate weaver I was ready to make the move from beginner portable table looms to a loom I could live with and I aspired to create larger tapestry style pieces. Loom choice is a very personal preference, depending on what it is one will be making and one's level of skill or ability. One of the biggest constraints in urban Aotearoa New Zealand is household space. For some, when your family has fledged the nest there are spare rooms to take over as hobby rooms in which to install floor looms; however, these are large, heavy cumbersome items and expensive to buy new. But what of the home-weaver who wishes to share living space within the demands and the normal flux and flow of family living. How does one bring a loom inconspicuously into the living room? To add to this challenge I needed a compact loom with multiple shafts. Additionally, I wondered, would it be possible to have an *upright loom* with multiple shafts?

For home loom-builders, the go-to plans are for the Flying8 DIY loom, designed and sold by Estonian loom creator Andreas Möller. First developed in 2009 as a 'space-saving' counter-march style loom, the Flying8 loom has become a valuable tool in start-ups and social enterprises all over the world including developing nations (Weberei Hamburg, n.d.). As you can see in Figure 1, this Dunedin example built by Master weaver Christine Keller, the Flying8 DIY loom is still a room sized piece of joinery with a big footprint (Keller, 2013). Floor looms by design are meant to be a permanent fixture in a room and are not designed for moving quickly without dismantling them. Both its size and weight made it unsuitable for sitting quietly amongst a family at work and play. This was not going to be a suitable loom for my situation.

Figure 1. The Flying8 DIY loom design by Andreas Möller.

Figure 2. An example of a simple rack or upright loom. This piece was made for an Art+Science collaboration with Dr Anna Kluibenschedl (left) whose research area is coralline Algae. Dr Ro Allen on the right. (McKinlay with Kluibenschedl, 2019).

Figure 3. Navajo-Weberinnen in der Navajo Nation Reservation, Mai 1972. Holdings of the National Archives and Records Administration, cataloged under the National Archives Identifier (NAID) 544416. Environmental Protection Agency image in the Public Domain.

The simple free-standing vertical or upright loom in Figure 2, is the simplest of constructions. It is basically a rectangular frame with an upper and lower beam between which the threads are wound and stretched. This kind of loom, which can be used for tapestry, was the basis for the developments described in this article. The loom in this photograph also pulls apart for easy storage between projects. Many of the available manuals such as *Vertical Loom – Principles and Construction* (1989), by Jules Kilot, were also based on a single top bar loom as pictured, such as used in Navajo weaving, an example of which can be seen in Figure 3.

Tapestry weaving involves a technique where each warp strand is manipulated by hand, which is very time-consuming. I looked for answers on how to speed up this process, with the creation of additional weaving 'sheds' in traditional weaving books. The perceived wisdom was that two shafts could be created easily using a combination of a weaving 'stick' and leashes (see Figures 4–6). The first shed is easily achieved by weaving a long stick through every second thread and turning it on its side. The second shed is made by looping and knotting a series of leashes to every second thread which when pulled creates the opposing shed. When a shed is made, one or more shafts move in opposition to each other to create an open space through which to pass the weft thread.

SOLUTION PHASES

CREATING THE LOOM: PHASE ONE

The development of this upright loom began innocently enough with a request to Joanna Wernham, joiner and designer, for "two long weaving sticks" to create this shed effect. The ensuing request inevitably snowballed into discussions and experiments, which eventually led to the progressive development of the loom that inconspicuously fitted into my living room. But could there be multiple shafts and how would we create that shed to weave through?

It immediately became clear that rollers would be the first item to be added onto the existing rack loom. Rollers allow longer lengths of cloth to be woven but also enable sufficient tension to be applied to the warp. Spare parts salvaged from old and broken looms were used for the ratchet handles, and rollers were created as bespoke pieces to suit the given dimensions (Figure 4).

Figure 4. The addition of rollers to the rack loom, using recycled loom parts.

Figure 5. The use of a stick and pole to create a shed.

Figure 6. We explored a range of frames for holding the "sticks" to create a shed in the weaving.

Figure 7. Tying leashes.

Figure 8. Shafts moving in two directions to create shed.

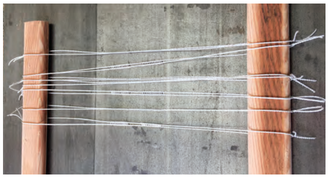

Figure 9. Textsolv heddles.

Figure 10. (Left) Finding alternatives to leashes: "steam punk".

Figure 11. (Right) Exploring and testing the various options was all part of the fun.

Resolving the problem of creating an easily managed shed, took weeks of exploration, simply because we could, we were having fun!

The first iteration was the initial request of a 'stick' and leash pole (Figure 5). The second iteration used leashes and creation of a range of frames into which the sticks were placed to open the shed. One idea was to have two leash poles working on opposite sides of the warp, but really, how would you operate this in practice! (Figures 6 and 7). The third iteration was to create what we called our *steam punk* system to insert each warp thread into (Figure 10). These wooden heddles could be moved backwards and forwards to create the shed. It was cool but quickly dismissed as a viable option, because actually how would they be connected together in such a way that could be easily operated?

We did play with a few other options, but the final iteration was the obvious, *"why didn't we do that in the first place!"* addition of two shafts using Texsolv heddles (Figure 9) to hold the warp threads. (Figure 12).

With the wisdom of hindsight, it now looked remarkably like an upright version of a rigid-heddle loom (Ashford Wheels & Looms, n.d.).

The sheds in this two-shaft upright loom were created manually by pulling one or other of the shafts towards the weaver and held in place by a manually inserted piece of curved wood until the next shed change. This was great for plain weave and several tapestry style wall hangings were created on this loom (Figure 12).

Following this success, we wondered whether we could add more shafts and thereby increase the complexity of the weaving and weave patterned rugs and twills in the Scandinavian style. See Bengtsson, Bjoerk & Ignell (2016) for examples of this style of weaving.

Figure 12. Loom with roller and two shafts containing Texsolv heddles. The shafts were manually operated and held open by a piece of curved wood.

RESEARCHING THE OPTIONS

Our process again was iterative as there was little information available about the actual practical mechanics of loom design that we could find. Research in weaving forums uncovered an upright loom design from Leicester from the 1930s called the Dryad loom (British Museum, n.d.). (Dryad is the Greek name for a tree spirit – *dryaed*). This loom is no longer made but some accounts record it had similarities to the LeClerc or Tissart Cantilever loom. Every recollection I have read of these looms describes them as being a very solid piece of furniture (some described it as the "battletank" of looms. This did not bode well for a loom that could sit inconspicuously at the centre of our household):

> Sturdy as hell, which well they should be. The beater doesn't slide but instead is on rails and is held up by springs, you pull it down to beat the shed. If you live in an upper storey, you'll drive your neighbours mad, but you could make a bunch of rugs to insulate the sound. The shafts move forward and backwards rather than up and down obviously. It's a very convenient system, but if you want to make your own and wish to simplify things you could try replicating the ancient warp-weighted system, which is similar in principle to the typical tapestry system (Kiernan, 2016).

PLATE 3. DRYAD FOOT POWER RUG LOOM.

Figure 13. The Dryad Loom – a solid piece of kit. The Dryad Works also published a series of leaflets covering various crafting techniques including several on loom weaving which featured its looms. Image source: Dryad Press series 85.

Figure 14. Amasis Painter, ca, 550–530,
black figure terracotta with scene of textile work.

Figure 15. Christina Petty at her loom –
Most tapestry looms have a triangular brace for stability, but this increases the footprint.
Here Christina uses a tree, which would also be unsuitable for a living room solution.

The writer in this account continued that if they wanted another loom such as this, they would make a warp-weighted loom. To follow this clue, I would need to go back in time to uncover the workings of warp-weighted looms, which is as it turned out is a highly active area of practical archaeology.

All cultures have a history of weaving. Many will be familiar with the legend of Penelope in ancient Greece through to the many goddesses of weaving in countless pantheons such as Frigg (Norse). It is suggested by Postrel in *The fabric of civilization: How textiles made the world*, that the stone age could be renamed the 'string age' to honour the place and importance of textiles in the development of trade, economy and civilisation (Postrel, 2020). It is one thing to consider the imagery of Penelope on an ancient Greek pot and quite another to encounter reproductions of warp-weighted looms created by practical archaeologists. Penelope's loom is depicted in another ancient Greek pot (Penelope at her loom with Telemachos, Athenian red-figure cup, *c.* 440 B.C.E., by the Penelope Painter), which is the subject of practical reconstruction. The Penelope project aims to integrate ancient weaving into the history of science and technology. There is also the pracademic research of Alexandra Makin and Christina Petty, who have created a multi-shaft, warp-weighted loom for achieving simple twills as well as plain weave. While there is an active global community researching warp-weighted looms and techniques from antiquity, their research and loom design had resolved a longstanding mystery between how ancient textile fragments in museum collections were created and the longstanding view that these would have been impossible to produce on warp-weighted looms (but then how to explain the twill fragments that exist – a prehistory and archeology paradox) (Makin, 2020). While intellectually fascinating, the shifting of the weight of the weaving sticks and clanking of heavy stone weights in my living room was also not going to be a solution.

CREATING THE SL-LOOM: PHASE TWO

Joanna Wernham (mentioned earlier) picks up the story:

"So, if we could make a two-shaft loom, why not make it four? How hard could that be, and how would the shafts be operated? The initial trial maintained the shaft 'castle' in the horizontal plane, now including hand operated levers to control the action (Figure 16). Trying to figure out how to do this using foot operated pedals was not really an option to incorporate into the original rack loom design. So recycled lever components clamped in place, different methods of making each shaft move forwards then back again was the challenge. Having the shaft move forwards was one thing using the lever, to have it return quite another. Maybe a spring or possibly bungee cord? But the tension required to get the shafts back into the castle proved too much for the system to function fluidly. The clue was in the Dryad loom, by putting the castle on an angle and to allow gravity to help in the return process, the shafts almost slid back into place once released by the levers. The next innovation was to add weights to the shafts to assist in this process."

Figure 16. Horizontal castle, demonstrating using the lever with bungee cord.

"Having the castle on an angle was the solution, thank you to the Dryad designer! But in doing so the heddles also needed to be aligned vertically for the warp to run through the four shafts to work properly and using my grandfather's brass plumb-bobs were essential in that alignment process. The second plumb-bob (to the left, Figure 17) was used to work out the placements of a series of screw-eyes for the lead weight lines to be run. This maintains an even tension and clean shed. The inspiration for this was taken from the ubiquitous double hung windows found throughout the Edwardian houses in Ōtepoti Dunedin – double hung windows in which the upper and lower window sashes slide vertically. The movement in early double-hung sash windows was produced by counterbalanced cylindrical weights suspended on cords that run to the top of the frame and into a cavity beside the window. However, our movement was in two planes hence the requirement for a pulley system to distribute the movement (Villa Windows, n.d.)."

Figure 17. Angled castle, showing the use of plumb-bobs to align the heddles and setup the lead lines.

CONCLUSION

This article followed the iterative development of an upright hand loom. As written records were scarce, the loom was designed by a process of experimentation and iterative changes to the design in the workshop, followed by threading the loom and weaving a sample to see how the loom was performing at the thread-face. Given that written accounts of loom design are so poorly represented in design and weaving literature and we were unable to find any useful direction from the writing we could find, we give an account here with detailed illustrations of our working findings so that others may follow, make their own changes and improve upon this design, without needing to reinvent the wheel as it were.

Tapestries require a high-tension warp to allow the weft to flow around the warp instead of deflecting it. And so here we have the final result after much trial and error, many cups of tea and remarkably little swearing. It is a sturdy and uncomplicated loom. We have used a metal reed in a wooden batten frame (usually used to beat the threads) as a means to separate the threads and keep them evenly spaced but not as a beater. Beating is done with a wooden rug fork. The rug fork I use is a heavy wooden implement with the handle at an angle to the head. The warps are on rollers for tension and moved forward by a pawl and ratchet system adjusted by a hand crank/wheel.

This loom has fulfilled the goal of creating an apparatus to weave more complex patterns at a larger scale. The loom is compact and quiet. The design is bespoke. It has beauty with function. We present the CUWL loom and have woven our first samples.

Figures 18–19. Photographs of the final solution – the compact upright weaving loom.

ACKNOWLEDGEMENTS

The project on which this article was based was a creative partnership with **Joanna Wernham**. Joanna has an extensive background in design, in print, hard media and product design. She has worked in the past for the Design Studies and Foundations Studies, University of Otago. Joanna is a member of Dunedin's LoomRoom as both a weaver and loom technician and is also renowned in Dunedin for her creativity in the world of miniature furniture making.

Pam McKinlay is a weaver and textile artist with a background in applied science and history of art.

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REDUCING CAMPUS CARBON FOOTPRINTS

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ABSTRACT

Organisations are now focussing on strategy with more sustainable operations, now that pandemic uncertainties and lockdowns are less unpredictable. To balance strategy and risk, business intelligence and data-driven, decision support is needed. This article considers tertiary campus emissions based on a yearly summary report, where emissions are measured and monitored for mitigation. The data problem is framed, so that linear regression, clustering and a basic semantic analysis can lead to further insights. The discussion and rationalisation lead to future-based conclusions. Temporal emissions analysis is recommended for similar organisations. The article also finds that even in the tertiary education sector, unique circumstances may lead to a shift in focus, anomalies or unique strategies to reduce operational emissions immediately and in the longer term.

INTRODUCTION

The purpose of this article is to analyse a quantitative data set that can serve as a tool to help reduce organisational greenhouse gas (GHG) emissions. The report focusses on critically framing the data problem generally, from the perspective of a tertiary campus. The data are used to consider issues, and the application of data driven techniques is evaluated and used to justify insights, conclusions and recommendations.

Greenhouse gases can lead to global warming and have serious and existential consequences. Thus, the global response is to limit GHG emissions and global warming to 1.5°C, with the aim of constraining modulation in land, air, and water ecosystems. If the '1.5 degree threshold' is breached, sea levels will rise, and life-threating heatwaves and other natural disasters are likely to result (Aydos et al., 2020). Socially responsible businesses are becoming more proactive in emissions mitigation efforts, and finding innovative ways to operate more sustainably. Failure to act will increase the potential risk within organisations and may lead to sanctions, levies, or other negative repercussions. This article offers recommendations, for organisations, that are particularly useful in any tertiary campus towards the goal of reducing emissions.

This article frames the data problem with a methodology that supports data description, linear regression, clustering and semantics, with discussion, rationalisations and conclusions.

FRAMING THE DATA PROBLEM

Greenhouse gases are typically compound gases released into the atmosphere that have an ability to trap longwave radiation or heat in the atmosphere, which causes 'Global Warming' as a consequential result (Jonas et al., 2019). The Intergovernmental Panel on Climate Change (2018) signalled considerable additional damage of 2°C warming over 1.5°C, highlighting the short time left to avoid exceeding the lower threshold. Crossing the 1.5°C limit will accelerate the climate change disaster (Aydos et al., 2020). Therefore, it is a responsibility of businesses globally to reduce their emissions. This can be viewed as a genuine opportunity; failing to take action now creates more risk for organisations and may lead to fines and sanctions.

The data used to frame the problem is the 2021 emissions report of the University of Otago in Aotearoa New Zealand, including the years 2019 and 2020 (University of Otago, 2021). It contains many data graphs and highlights the 'Total Emissions' by tonnes of Carbon Dioxide emitted (tCO_2e) and 'Proportion of Total Inventory.' Summarised data are given for 2019 and 2020 in Table 1.

The data are grouped by Scope 1, Scope 2 and Scope 3 for 2019 and 2020 emission sources. An emissions inventory is a way of accounting for the air pollutants discharged into the atmosphere (World Health Organisation, n.d.). When sources of emissions are divided into the three main scopes, they can be viewed from different operational levels; the sources are categorised by the GHG Protocol (GHGP) (Standard, 2011), the premier guide for carbon accounting and are as follows:

- Scope 1 are direct emissions come from owned or controlled sources by the reporting company.
- Scope 2 are indirect emissions come from the generation of purchased electricity, steam, heating, and cooling used by the reporting company.
- Scope 3 are indirect emissions that occur in a company's value chain, outside of the reporting company's walls.

Three data perspectives have been used to frame emissions considerations and focus different abstract challenges as well as actionable opportunities. By articulating the viewpoints by scope, it is possible to conceptualise various emissions risks. Aligning emissions mitigation with business strategy requires understanding the sustainability expectations of the wider community, and suggesting actionable recommendations that include potential opportunities within future commitments (Spradlin, 2012).

In this study, three considerations were explored via data.

1. ***The impact of direct and indirect greenhouse gas emissions***

   By identifying the amount of emissions generated by the sources owned/controlled by the university and the indirect sources (from purchased electricity, heat, and steam consumed), the management can measure the total amount of CO_2 generated each year, against the total cost spent on maintaining/running those sources for the same length of time. Priority should be given to reducing the impact of top emission sources in these two categories. As the sources in these two scopes are owned/controlled, the management can analyse the current impact, then try using different or other sustainable practices in the future, to see the amount of emission reduction and the cost for implementing the changes accordingly. This will enable the campus to measure the success of newly implemented greenhouse gas reduction practices towards cutting down on direct and indirect GHG emissions.

Emission Source	Category	2019 Emissions Reported (tCO_2e)	2019 Emissions Rebaselined (tCO_2e)	2020 Emissions	% Difference (Rebaselined 2019 to 2020)	Proportion of Total 2020 Inventory
SCOPE 1						
Stationary Combustion	Biomass	66	69	64	-7%	0%
Stationary Combustion	Coal	1,559	1,559	1,384	-11%	5%
Stationary Combustion	Diesel	78	78	58	-26%	0%
Stationary Combustion	LPG	1,276	1,276	1,116	-12%	4%
Mobile Combustion	Road Vehicles	226	228	168	-26%	1%
Mobile Combustion	Marine	17	18	21	+14%	0%
Fugitive Emissions	Refrigerants	106	106	109	+3%	0%
Total Scope 1		**3,328**	**3,334**	**2,920**	**-12%**	**10%**
SCOPE 2						
Electricity	Electricity	4,628	5,082	5,427	+7%	18%
Steam & MTHW	Coal	5,257	6,176	1,226	-80%	4%
Steam & MTHW	Biomass	273	273	417	+53%	1%
Steam & MTHW	Natural Gas (Wellington)	NA	260	181	-31%	1%
Total Scope 2		**10,158**	**11,791**	**7,251**	**-39%**	**24%**
SCOPE 3						
Transmission & Distribution Losses	Electricity	350	385	467	+21%	2%
Steam & MTHW Losses	Coal	263	309	61	-80%	0%
Steam & MTHW Losses	Biomass	14	14	21	+53%	0%
Steam & MTHW Losses	Natural Gas (Wellington)	NA	30	11	-63%	0%
Business Travel	Air Travel (All Categories)	11,894	11,982	1,699	-86%	6%
Business Travel	Accommodation	269	338	115	-66%	0%
Business Travel	Taxis & Shuttles	82	64	36	-43%	0%
Business Travel	Private Mileage	142	142	71	-50%	0%
Student Travel	Air Travel (All Categories)	NA	11,244	9,143	-19%	30%
Employee Commuting	Public Transport	47	69	76	-10%	0%
Employee Commuting	Private Vehicles	1,434	1,548	1,320	-15%	4%
Student Commuting	Public Transport	NA	187	147	-21%	0%
Student Commuting	Private Vehicles	NA	957	755	-21%	2%

Table 1. Campus greenhouse gas emissions inventory by scope.

2. *The impact of business travel on greenhouse gas emissions*

Business travel alone has eight different sources of emissions. Thus, efforts must be made to measure the total impact of business travel on the overall carbon footprint. Doing so could be a potential sustainability and a financial breakthrough for the organisation. With the impact of business travel so high, management must make efforts to improvise, adopt and overcome the emission activities with new technologies. Adopting technological advancements to replace business travel in terms of interacting with audiences could potentially be highly cost-efficient as well as environmentally friendly.

3. *The impact of working remotely from home*

Pandemic lockdowns accelerated online ways to work. The practicality of remote work for emissions reduction (excluding business travel) was considered. Employees now working from home during the COVID-19 global pandemic compelled organisations to think of working from home as the new normal. It reduced office operational costs as well as commuting-based emissions. Management must figure out which employees are working from home, which energy sources are consumed, how often they are consumed and how much emissions are caused as a result annually. This type of analysis could be a game changer in terms of overcoming costs associated with office maintenance and reducing the overall emissions by a considerable margin.

METHODOLOGY

The University of Otago data was already summarised. The original 2019 data was focussed on the University's main campus in Dunedin and the services that were administered there. The 're-baselined' 2019 figures in the report were the ones that we utilised; some null entries became populated, as data for all of the campuses were included (in line with the 2020 data), making comparisons more relevant.

The data in 2019 (re-baselined as 2019r) and 2020 were compared using a number of analytical techniques (data description, simple linear regression and clustering). The three considerations were reflected on, in light of our findings. A simple semantics analysis was included using a text inquiry; the intent was to explore emissions mitigation from the standpoint of a Scott and Jaffe Change Model.

The three impact considerations were then reflected upon in the context of the University report (University of Otago, 2021) as a whole, to yield insights. Conclusions and recommendations are given.

DATA DESCRIPTION

The descriptive statistics in Table 2 are for 2019r and 2020 with only the subtotals removed. An improvement is noted (lower mean, standard deviation and maximum) in 2020; this is to be expected, and was seen globally due to the initial COVID-19 lockdowns in 2020 (Aktar et al., 2021). The real management question is, when delivery on campus resumes, will emissions mitigation strategies be reactivated?

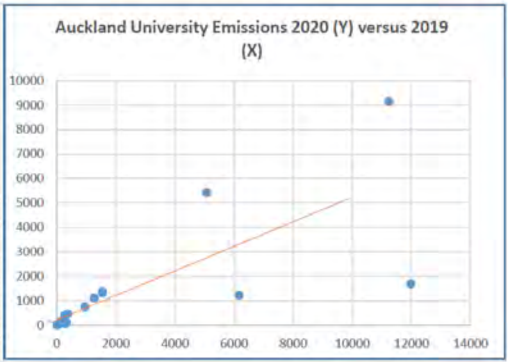
The greatest emissions, with the highest proportion of inventory is emitted by 'Business Travel (Long Haul International)' and the lowest amount of emission with the lowest proportion of inventory is emitted by 'Waste from Operations (Recycling and other).'

2019 REBASELINED		2020	
Mean	**1766.416667**	**Mean**	**1003.875**
Standard Error	695.600116	Standard Error	424.0236155
Median	266.5	Median	157.5
Mode	69	Mode	21
Standard Deviation	**3407.730699**	**Standard Deviation**	**2077.282994**
Sample Variance	11612628.51	Sample Variance	4315104.636
Kurtosis	4.758522407	Kurtosis	11.06630629
Skewness	2.363097947	Skewness	3.252523859
Range	11968	Range	9132
Minimum	14	Minimum	11
Maximum	**11982**	**Maximum**	**9143**
Sum	42394	Sum	24093
Count	24	Count	24
Largest(1)	11982	Largest(1)	9143
Smallest(1)	14	Smallest(1)	11
Confidence Level 95%	1438.958474	Confidence Level 95%	877.1596792

Table 2. Descriptive statistics for 2019r and 2020.

LINEAR REGRESSION

Regression analysis is a crucial technique to that allows you to study the affiliation between two more variables on a particular topic or area of interest, in terms of closely monitoring the impact of each variable on each other (Freund et al., 2006). In order to consider any relationship between 2019r and 2020 in the selected dataset, a simple linear regression technique was adopted. Table 3 has the summary output of the regression.



REGRESSION STATISTICS	
Multiple R	0.750531921
R Square	0.563298164
Adj. R Square	0.542502828
Observations	23

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	55386649.35	5.5E+0.7	27.08773	3.7032E-05
Residual	21	42938985.09	2044714		
Total	22	98325634.43			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95%	Upper 95%
Intercept	201.9854384	339.2938998	0.59531	0.557997	-503.61485	907.58573	-503.61485	907.58573
SLOPE	0.457964204	0.087992413	5.20459	3.7E-05	0.27497396	0.6409544	0.274974	0.6409544

Table 3. Polytechnic 2020 emissions (2019r as x variable).

The correlation statistics show good linear relationships between the two years and a highly significant model, being:

$$2020 = 0.458\ (2019_r) + 202 \quad (1)$$

The slope indicates an emissions reduction in 2020, but this is likely due largely to COVID-19 lockdowns. The large values (from left to right on the scatter plot) are Scope 2 Electricity and then Coal with Scope 3 Student Air Travel and then Business Air Travel (all categories) respectively. In terms of using the regression analysis for predictive modelling, it is likely that the data should be pre-processed by categorising emission types further, as well as exploring scopes (Cherrington et al., 2020).

The scatterplot serves as a stark visual representation of the data, possibly more important than the predictive model (Tufte, 1985). Increasingly, data scientists are finding innovative ways to visualise data alongside results and to 'tell the data story' for impact and to compel action, especially climate action (Ojo & Heravi, 2018).

DATA CLUSTERING

The clustering technique used to analyse the University of Otago data set is k-means clustering, as in Table 4.

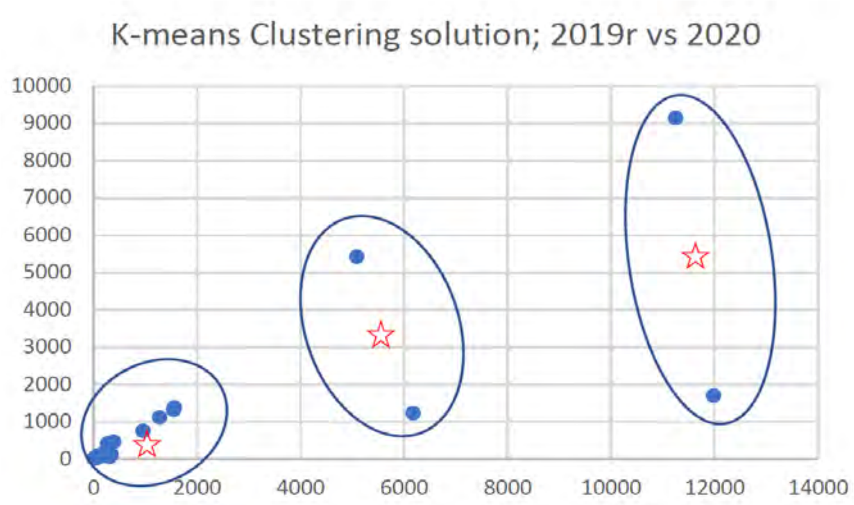


Table 4. Data clustering for 2020 versus 2019r

K-means clustering is an unsupervised learning algorithm, dividing the unlabelled dataset into different groups by analysing similarities (Pace & Cherrington, 2020); 'k' denotes how many predetermined clusters must be created in the iterative analysis. Here, k=3, which means three clusters will be created for the selected data set. This is reasonable, given the scatterplot. Obviously, the low emissions will become one cluster, but will the algorithm deal with the four high emission totals by grouping by Scope 2 and Scope 3? Indeed, that is the result, as in Table 4 with 'centroids' labelled for each cluster. Centroid 1 is [994.5,329.9], Centroid 2 is [5629,3326.5], and Centroid 3 is [11613,5421]. These are useful for comparison.

SEMANTIC ANALYSIS

For organisations engaged in climate action, a cultural shift is taking place. Analytical tools, text and semantic analyses are becoming commonplace in organisations and are often used to gauge stakeholder opinion and even to change policy (Madanian et al., 2021).

The report was sampled for descriptive text, grouping emotive text such as 'difficult', 'tackle', 'interest' and 'ensuring.' Such text may be categorised as belonging in the 'deny', 'resist', 'explore' and 'commit' quadrants of a Scott and Jaffe Change model, respectively. The 2 x 2 categorisation can be thought of as a tool to gauge organisational focus for change management. A deeper semantic exploration can attempt to quantify the emotive content of text, or explore stakeholder comments, so as to "listen for the future" of the organisation (Kiesling, 2022) or lead to better alignment and investment (Zaffron & Logan, 2011) including more innovative leadership (Cherrington et al., 2021).

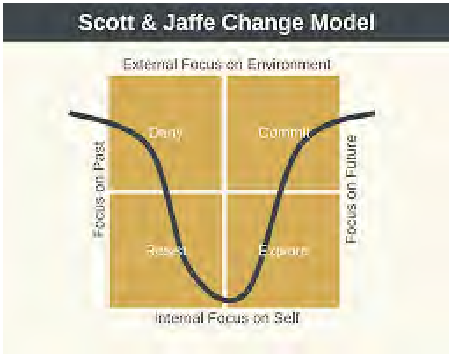


Figure 1. Scott and Jaffe change model link with semantic analysis.

Analysis of eligible text put eight per cent in a 'deny' category, 18 per cent in 'resist', 42 per cent in 'explore' and 32 per cent in 'commit' quadrants, respectively. This shows a strong future focus for the University of Otago on emissions mitigation, as well as some tendency to internal focus with respect to emissions reduction.

DISCUSSION AND RATIONALISATIONS

The k-means clustering easily determined which emission sources were the least contributors to emissions in 2019r and 2020, which sources were the moderate contributors and which sources were the high contributors. Clustering can support feature selection pre-processing (Cherrington et al., 2019a) as well as revealing data outliers (Cherrington et al., 2019b). This could be seen in Table 1 as well, but the visual display of quantitative information adds to the storytelling of motivated action and even transformational leadership (Cherrington et al., 2021).

The determinations and assumptions that underpin emission sources and scopes is critical for any organisation seeking to measure, monitor and mitigate their emissions (Cherrington et al., 2020).

The emissions groups within Clusters 1, 2, and 3, rated as lowest, moderate and highest, could be contended with differently. There are many groups in Cluster 1 whose sum makes an impact; actioning these emissions may be 'low hanging fruit', creating 'short-term wins' to shift the culture of an organisation (Kotter, 2012). Failure to consider such opportunities has been identified as a cultural barrier to change (Cherrington, 2020a; Cherrington, 2020c).

Clustering and descriptive statistics highlighted that emission sources that were identified as 'Direct & Indirect GHG Emissions' had a combined contribution of 38.6 per cent of the overall carbon dioxide (CO_2) emissions, while the emissions from 'Business Travel' alone singlehandedly contributed 35.5 per cent of overall CO_2 emissions in year 2019r.

Sources from 'other indirect GHG emissions' (excluding business travel) contributed to overall CO_2 emissions in year 2019r by 25.9 per cent. It is clear, all the sources that relate to 'business travel' are the highest contributors to the overall carbon footprint, while the sources of 'direct & indirect GHG emissions' combined are the second highest contributors to overall GHG emissions. The majority of emission sources relating to business travel and emissions from steam, purchased electricity and heat consumed by the University of Otago were well above the mean value of 1165.37 tCO_2e.

CONCLUSIONS AND FUTURE WORK

In conclusion, 'Business Travel' is the biggest single emission source and is a considerable area of concern for mitigating future emissions impacts. However, adopting digital/online interaction platforms like Microsoft Teams or Zoom for audience interactions while restricting short air travels could significantly reduce the overall carbon footprint by approximately 70–80 per cent. 'Direct & Indirect GHG Emissions' collectively contributed to 38.6 per cent of overall CO_2 emissions, thereby it must be a focus for emissions mitigation.

Initiatives such as the usage of energy-efficient lighting and sustainable space heating control practices create quick wins in terms of emissions reduction. Furthermore, as 'Other Indirect Emissions (Excluding Business Travel)' contribute a just over a quarter of overall carbon emissions, it is projected that working from home could almost halve travel emissions.

A temporal emissions analysis can be used to create more effective policy on business travel, but most organisations will have unique circumstances that lead to shifts in focus for unique strategies to reduce operational emissions.

The data analytic techniques and approaches used here are simple and reductive, yet they help visualise the data. The analysis helps managers make short-term and long-term strategic decisions towards promoting sustainable practices to radically reduce the impact of business operations on emissions which lead to global warming.

Future work will delve into emissions data for other tertiary campuses, especially from societal perspectives (Naviza et al., 2021). A temporal exploration will support better understanding of the evolving emissions landscape in the sector and will support more focussed strategies for campuses via data-driven decisions. A firm intention of Scopes 2 and 3 emissions analyses is also needed for most organisations going forward to meet net zero targets nationally and towards global goals.

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