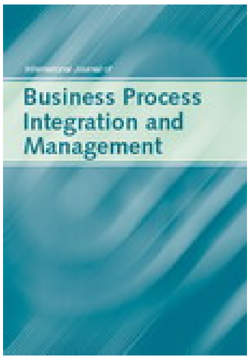

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Arnesh Telukdarie, Megashnee Munsamy

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Multi-objective business process optimisation: a business sustainability approach

Arnesh Telukdarie* and Megashnee Munsamy

University of Johannesburg,
Johannesburg, 0001, South Africa
Email: arnesht@uj.ac.za
Email: mmunsamy@uj.ac.za
*Corresponding author

Abstract: Business models have evolved from financial centricity to triple bottom line (TBL) centric. The challenge is the quantification of all business activities, as contributing to TBL, and predicting optimisation interventions to maximise TBL benefits. This research adopts 4IR tools to predict TBL optimisation. Chemical and business process sciences are integrated in developing a 4IR based predictive model to forecast the impact of change on TBL. Business processes capture business activities to develop a model representing the business. The model outputs are adopted to develop objective functions for the economic, environmental, and social aspects, for the multi-objective TBL optimisation. The reference TBL is defined, with the optimised TBL targets determined by reverse engineering the objective functions. The model is applied to a logistics business, which forecasts savings of 28 to 44 million rands (USD 2–3.2 million), 3,000 to 5,000 tons CO_2 emissions reductions and 30,000 to 53,000 man-hours reduction.

Keywords: business sustainability; triple bottom line; TBL; business processes; modelling; optimisation; energy.

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Biographical notes: Arnesh Telukdarie is a Professor of Digital Business at the Johannesburg Business School, University of Johannesburg. He is also an Adjunct Professor at Johns Hopkins University and as a Visiting Scholar at London South Bank University. Born in Durban, he completed a Doctorate in Technology in Chemical engineering and is a registered professional. He has published over 300 peer reviewed publication. He is a consultant and a research leader in digital transformation.

Megashnee Munsamy is an undergraduate and Master's study is in Chemical Engineering, with her DPhil in Engineering Management. She has industrial, academic, and consulting experience. Her consulting experience has focused on the digitalisation of business considering the environmental, economic and social aspects. Her current research areas are business digitalisation, ESG and systems modelling for healthcare optimisation.

1 Introduction

Business is a key global driver of economies and employment, deliverer of technology, products and services, and a contributor to global financial sustainability and environmental and social impacts (Aliabadi and Haung, 2020). Thus, the world of business is complex (Ng et al., 2019). Businesses must take a much broader perspective beyond traditional boundaries. Contemporary businesses pursue sustainable operations, based on people, skills, equipment, energy, and various other resources. Business sustainability is not just about a single business activity but is a collection of multiple business activities that affects the entire business. Traditionally, financial sustainability was the priority, but environmental and social sustainability are equally important (Schulz and Flanigan, 2016). The integrated financial, social, and environmental sustainability is referred to as the as the triple bottom line (TBL) (Raza et al., 2021). The ability to understand impacts as early as possible or even to predict impact of change on a complex business could deliver significant decision-making powers (Rostami et al., 2017). This includes the power to decide on investments so as to prioritise; including the capacity to determine which investment has the most impact on the business TBL. The ability of a business to strategically navigate technologies is a significant challenge especially if the technologies are new (Furjan et al., 2019), and impacts to business unknown.

There is an increased focus by government and companies on TBL, with contemporary businesses focusing on the integrated business for meeting TBL objectives (Islam et al., 2022). Zaharia and Zaharia (2021) focus on an aggregated TBL covering the entire business. However, the fundamental challenge is the measurement or quantification of all the defined measure points for TBL. Schulz and Flanigan (2016) argue for the development of quantification metrics for the TBL including extractions and alignment to various current key performance measures from balance scorecards to organisational sustainable performance index. Reim et al. (2015) conducted an elemental study of product services and systems for business models. The research propositions the value of integrated products and services through technology and other systems. The value to the business TBL is proposed but no models are proposed. Engert et al. (2016) provides insights into an integrated sustainability approach specific to project management, with key findings that economic and environmental aspects have been a traditional focus but social has been lagging. Khuntia et al. (2021) develops an information systems (IS) integrated sustainability framework inclusive of human and supply chain. The work calls for a bold new approach to IT forwarding business and the TBL. However, the framework is based on literature and the model proposed is not executable. Alotaibi and Liu (2017) states significant more research needs to be conducted in this area.

Joyce and Paquin (2016) propose a business model that comprises three layers; economic, environmental, and social. The three layers are imposed into the business canvas or the conceptual platform of the business model. Joyce and Paquin (2016) argue the ability to integrate all other aspects of the business model with the TBL components horizontally and vertically creating a synergetic business model. This aligns to the 4th Industrial Revolution (4IR) conceptual approach of an integrated business, with horizontal and vertical integration (Butt, 2020). The key aspect of a 4IR aligned business is the ability to integrate the entire business (Chukalov, 2017).

The 4IR delivers sophisticated toolsets (Hai-Jew, 2018), such as business process (BP) simulation, that facilitate various aspects of business optimisation. BPs are plausibly connected and sequential tasks representing individual physical business activities (Hai-Jew, 2018). BP modelling is an effective approach for identifying improvement opportunities (Fischer et al., 2020). The activity performed by a business can be represented by activity maps or BPs. The processes, once drawn up, become a complex network of activities of the business with interdependencies. Resources required for each activity is captured, at each process step, these include people, time, energy, hardware and other. If the resources are quantified for a specific business activity, then there exists an opportunity to optimise and reduce the resource utilisation. Single resource utilisation can be optimised, or all resources can be collectively optimised. If the network of processes is optimised, then the entire business can be considered optimised.

This research seeks to develop a model that comprehensively represents a business and adopts multi-objective optimisation techniques to predict and improve the TBL of a business. The research develops a representative model that has the capacity to guide strategic business interventions. The proposed multi-objective model (MOM) is ideal to determine the sustainability impacts of technical and other interventions. The key objective of this study is to provide a simplistic approach to model the sustainability of the holistic business, not the individual systems as traditionally conducted.

2 Methods

This study develops a predictive model for TBL optimisation. The predictive model is based on the development of a BP model representing the business. BPs stipulate the execution sequence for realisation of business outputs (Gross et al., 2019). BPs are categorised hierarchically, from a strategic level (level zero) to a shop floor level (level *n*).

A logistics business is rendered from a strategic level down to the shop floor level, as per Figure 1. For the logistics business, a four-level BP hierarchy is developed, with level 0 representing the functional areas of logistics, human resources (HR), sales and marketing, finance, operations. The L0 is expanded into a L1 of BP areas such logistics strategy, scheduling, inbound material flow, and fleet management. The L1 is expanded to L2 of BPs, with the execution of a BP achieving a specific business output. L3 is the BP step, which refers to each step of the BP. The constituents of a BP can be rendered by equation (1).

$$BP = \{P0_1, P0_2, P0_3, \ldots, P0_N\} \tag{1}$$

where $P0_i$ – BP at level '*i*'.

Each activity performed by the business requires resources such as people, energy, raw materials, intermediate materials, fuel, infrastructure, and operational equipment. To determine the resources required for each business activity performed, a resources list is captured for each BP step, as illustrated in Figure 1. For this study the resource requirements are categorised as HR, energy, time, resources, and hardware, as illustrated in the key in Figure 1 (bottom left). Resources refer to the specific equipment required to execute a BP step such as a barcode scanner or scale. Hardware refers to the information and communication technology (ICT) requirements of computers, switches, or gateways. Energy is the energy required to operate the identified resources and hardware. Time is the time taken to execute a BP step (operational time of equipment and hardware and personnel time) and HR is the number personnel required to execute a BP step. The comprehensiveness of BPs enables quantification of electrical energy demand, fuel demand, carbon dioxide emissions and personnel.

The BPs are simulated as per the number of business activities, resources required, variables and frequency to determine the three TBL functions.

- costs (economic function), *CEI*
- environment (environment function), *CEnI*

- personnel (social function), *CSI*.

In evaluation of the three factors of social, environmental, and economic the following are considered:

1 *Economic*
   - The economic factor quantifies the business expenditure, which are categorised as people, energy, and production costs.
   - People costs are a function of the personnel level and time contribution.
   - Energy costs are dependent on fuel and electricity usage.

2 *Environmental*
   - The environmental factor is based on the CO_2 emissions of the enterprise, a function of the electrical and fuel demand.

3 *Social*
   - The specific personnel requirements of a business are vast, with each business division requiring specific skills and educational requirements.
   - The personnel requirements are categorised as; executive, senior manager, manager/technical lead, supervisor/technical and operator.
   - The personnel level and respective time contribution in execution of business activities are considered in quantification of the social factor.

3 Model development

Whilst BPs form the foundation of the model development, the TBL prediction model comprises various tools applied sequentially. The tools deployed for the TBL business sustainability forecasting include;

- BP model development: BPs models are developed for every activity conducted by the business, including all activity interlinks, hence providing a digital representation of the whole business.
- Monte Carlo: Due to the number of business variables, and each variable having a specific operational range, Monte Carlo Simulations are run to secure a steady state or a baseline.
- Ordinary least squares (OLS) regression: OLS regression is adopted develop objective functions for the three TBL factors of *CEI*, *CEnI*, and *CSI*.
- Multi-objective optimisation: MOO is adopted to determine and optimise the TBL of a business. MOO is also applied in identifying the states of the most significant variables, to achieve the improved TBL.

3.1 BP model development and Monte Carlo simulation

The business activity, as captured in the BP sequencing in Figure 1 is adopted to represent the business via an executable BP model. The model is constituted based on the functional areas of a logistics business; HR, logistics (L), quality (Q), cleaner production (CP), integration (I), finance (F_i), maintenance (M), and digital (D) options. Thus, the logistics BP model is a function of $\{HR, L, Q, CP, I, F_i, M, D\}$.

The BP model is influenced by variables ($x_1, \dots, x_n$), which contribute towards specific business outputs. For a logistics business, examples of the business variables include but are not limited to the number of deliveries (x_1), quality checks (x_2), orders (x_3), incidents (x_4), and invoice (x_5). As the number of variables are specific to a business, a variable set ($x_1, \dots, x_n$) is defined, with n representing the total number of variables.

The activities performed at a logistics company are neither linear or static, hence in execution of the BP model, randomness is applied to the variables, constrained to the upper and lower operational range of the variable. This introduces uncertainty in the model. Thus, Monte Carlo simulations are executed until the change in the standard error of the mean of the target output is negligible. For this study, the point of achievement of negligible change in the standard error of mean is defined as the reference state of the business.

3.2 Ordinary least squares regression

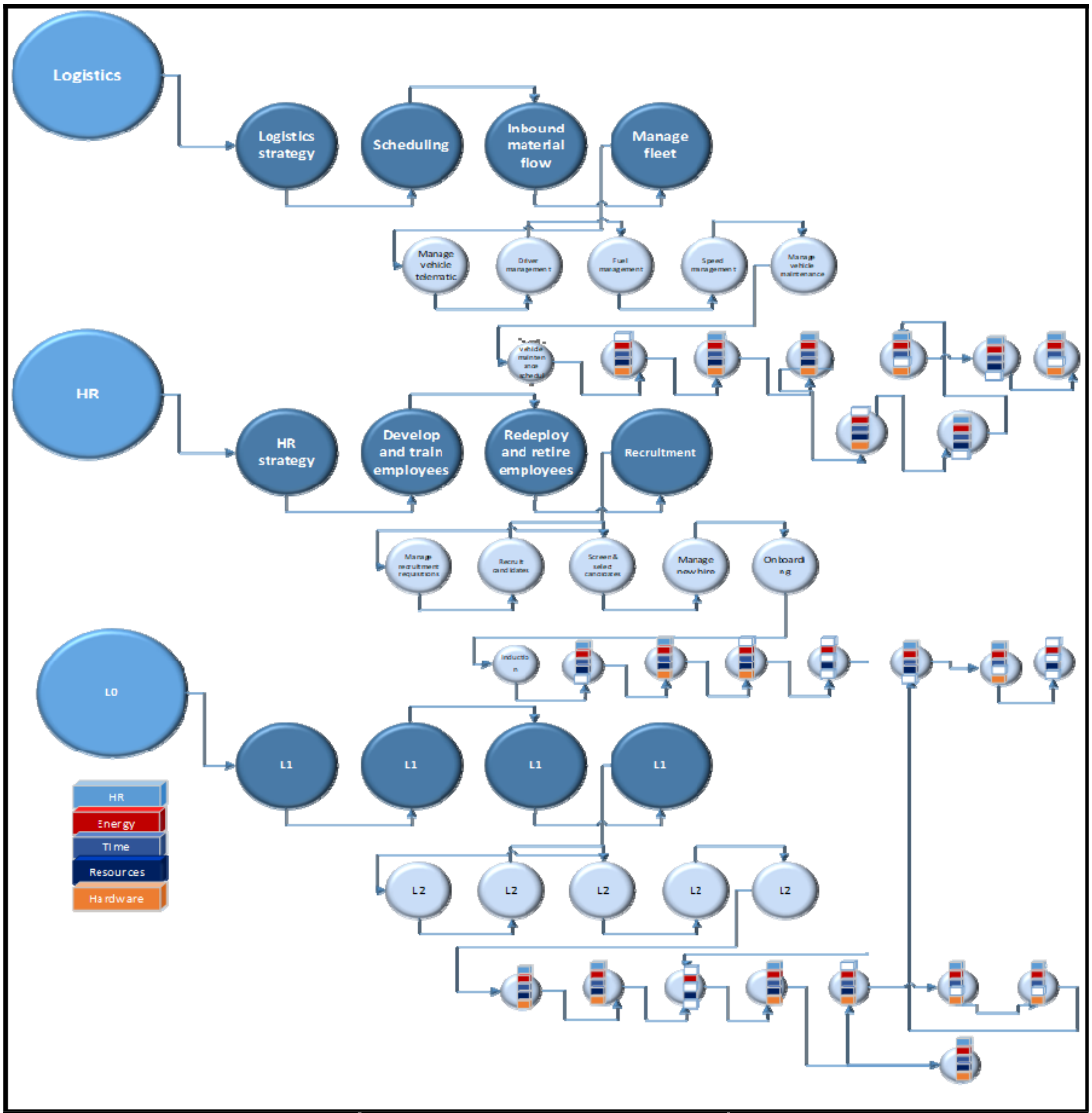
In execution of the Monte Carlo simulation, a data matrix ($m \times n$) is developed. For each run, every variable has a specific status (constrained to the upper and lower operational range) and associated outputs of costs, personnel hours, and CO_2 emissions. The data matrix is analysed using ordinary least squares regression (OLSR) to develop individual linear objective functions for the economic, environmental, and social factors, represented by *CEI*, *CEnI*, and *CSI*, respectively. Inherently in the OLSR analysis, only the variables significantly impacting each factor are selected.

3.3 Multi-objective optimisation

The individual objective functions are utilised in quantifying the sustainability status of the business as represented by the sustainability vector introduced by Moradi Aliabadi and Huang (2016a, 2016b, 2018a, 2018b). The composite sustainability indexes can be aggregated into a singular index defined as the business sustainability index (BSI).

$$\overline{BSI} = \langle CEI, CEnI, CSI \rangle \tag{2}$$

Figure 1 Rendition of BP hierarchy with resources defined (see key) (see online version for colours)



All the resources are required for this level 3 activity (HR, energy, time, resources and hardware)	HR, Energy, Time, Hardware is required at this L3 activity	Only HR and Hardware is required for this L3 activity

The development of the MOM includes all three objective functions. The sustainability status of the business is a function of all business variables as discussed by Aliabadi and Huang (2020) and is described as:

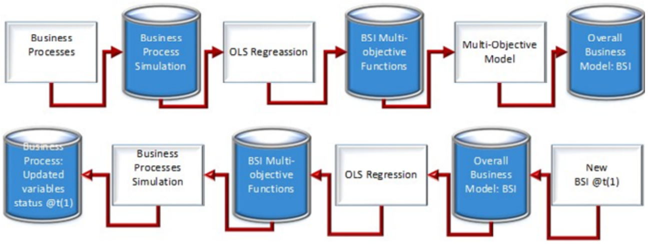
$$\overrightarrow{BSI} = \begin{bmatrix} CEI \\ CEnI \\ CSI \end{bmatrix} = \begin{bmatrix} f_1(x_1, x_2, \ldots, x_n) \\ f_2(x_1, x_2, \ldots, x_n) \\ f_3(x_1, x_2, \ldots, x_n) \end{bmatrix} \tag{3}$$

where f_1, f_2, and f_3 are the functions that describe the relationship between the sustainability status of the business and all the variables ($x_1, \ldots, x_n$) that affect the business. For this study BSI is adopted as the optimisation function for business sustainability. BSI can be calculated using the multi-objective scalarisation method (Gunantara, 2018). The weights are defined prior to optimisation and allows the development of a single output, which for this study is the BSI (Gunantara, 2018). The weights can be determined by a subjective weighting method, an objective weighting method, or a combination of both. The BSI is computed as per the equation below:

$$\begin{aligned} &\textit{Business sustainability index } (BSI) \\ &= w_1 CEI + w_2 CEnI + w_3 CSI \end{aligned} \quad (4)$$

where w_1, w_2, and w_3 are the weights associated to the economic, environmental, and social objective functions, respectively. As an initial assumption, an equal weighting is adopted for each of the factors.

Figure 2 Model framework (see online version for colours)



At each stage of business sustainability enhancement, a new sustainability goal is set ($BSI_{t(1)}$). $BSI_{t(1)}$ is an improved state of the reference BSI ($BSI_{t(0)}$), and is defined as a BSI lower than that at $BSI_{t(0)}$. The BSI at time $t_{(1)}$ is defined as.

$$BSI_{t(1)} = w_1 CEI_{t(1)} + w_2 CEnI_{t(1)} + w_3 CSI_{t(1)} \quad (5)$$

$$BSI_{t(0)} - BSI_{t(1)} = SIP \quad (6)$$

where

- SIP – sustainability improvement potential
- $BSI_{t(0)}$ is a function of $(x_{1(t(0))}, \ldots, x_{n(t(0))})$
- $BSI_{t(1)}$ is a function of $(x_{1(t(1))}, \ldots, x_{n(t(1))})$.

The variables determined at $t_{(1)}$ would be the target variable state to achieve overall improvements to the business as determined by the SIP. Figure 2 represents the process detailed above, including the sequential adoption of the various tools.

The model framework defines the overall model development, from BPs to a consolidated set of multi-objective functions for the BSI. The framework further illustrates how the model, once developed is executed (in reverse) as an optimiser.

4 Results

The key objective is to develop a predictive model to provide insights into the business variables impacting TBL. For this study, the BSI of a medium size logistics enterprise is selected for optimisation. The company receives orders for cargo movement via large, medium, and small trucks and rail. Operational constraints of the company include:

a The business comprises 120 commercial trucks (3.5 tons to 60 tons).

b A staff complement of 222.

c The business has 93 variables (x), each with a specific operational range.

d The states of the variables are dynamic and include (but not limited to):

- number of orders received per month
- fuel costs
- personnel costs
- time to deliver
- distance
- cancellations (orders, deliveries)
- fluctuation in fuel price
- performance of fleet vehicles
- operational costs
- environmental emissions
- personnel demand.

The company has to optimise operations to deliver on time, plan for resources and energy utilisation, and manage all services.

4.1 Development of the BP model

The BPs for the logistics enterprise is extracted from the American Productivity and Quality Control (APQC) (2015) process classification framework (PCF). APQC is a cross-functional repository of BPs, updated and validated. The BPs extracted from APQC is verified, modified, and validated by a logistics business implementation functional lead with the appropriate competency and experience. A view of the BPs as extracted and verified is in Appendix.

The logistics business is defined, and the BP models developed in Microsoft Visio. The key business functions are:

- Sales and marketing: Acquires new customers and promotes the business.
- HRs: Responsible for staff recruitment, development, and deployment.
- Integrated planning: Determines resource requirements and plans the movement of goods to meet customer demands.
- Logistics: Responsible for conveyance of goods from warehouse to customers, among customers and from customer back to warehouse (returns processing).
- ICT: Manages the hardware and software requirements of the business network.
- Financial Management: Manages all financial operations from invoice collections to salaries payments.

The business functions are unpacked from the functional category through to the activity level, refer to Appendix. All the activities performed in the logistics company is hierarchically and sequentially captured. In order to provide an indication of the number of activities captured, refer to Table 1.

Table 1 Number of steps for operation of the logistics business

Business function	*No. of process areas*	*No. of BP steps*
Integrated planning	1	18
Logistics	6	70
Sales and marketing	4	180
Human resources	5	134
ICT	5	89
Financial management	6	299
Total	27	790

Ninety three variables impact the execution of the 790 BP steps. The Monte Carlo simulation executes 2,400 runs to achieve negligible change in the standard error of the mean of the outputs. This creates a 2,400 × 96 data matrix, which is adopted for developing the individual objective functions and the multi-objective functions. 96 represents the 93 variables and three BP model outputs of cost, CO_2 emissions and personnel hours.

4.2 Development of the multi-objective functions

Using the 2,400 × 96 data matrix, the objective functions are developed to represent the economic, environment and social aspects of the logistics business. The OLS regression (run via Python) is applied to the data matrix, identifying 15 variables as having significant influence on the logistics business. The objective functions of the BSI factors of economic, environment and social are detailed below.

- *Composite economic index (CEI):* Calculates the annual operational cost in South African Rand (million ZAR).

$$\begin{aligned} CEI = {} & 554.76 + 48.55x_1 - 32.36x_2 + 0.77x_3 + 0.82x_4 \\ & +2.47x_5 - 0.12x_6 + 0.76x_7 + 1.77x_8 - 0.74x_9 \\ & -3.10x_{10} - 4.83x_{11} + 7.56x_{12} - 52.28x_{13} \\ & -136.28x_{14} - 17.30x_{15} \end{aligned} \tag{7}$$

- *Composite environmental index (CEnI):* Calculates the annual CO_2 emissions in kilotons

$$\begin{aligned} CEnI = {} & 66.76 + 7.96x_1 - 3.43x_2 + 0.6x_3 \\ & -0.009x_4 + 0.04x_5 + 0.004x_6 - 0.03x_7 \\ & +0.04x_8 - 0.04x_9 - 0.05x_{10} + 0.05x_{11} \\ & +2.6x_{12} + 0.46x_{13} - 23.68x_{14} - 4.5x_{15} \end{aligned} \tag{8}$$

- *Composite social index (CSI):* Calculates the annual required personnel hours in thousands of hours

$$\begin{aligned} CSI = {} & 615.07 + 18.14x_1 - 35.62x_2 - 6.47x_3 \\ & +0.90x_4 + 8.5x_5 - 1.70x_6 + 6.27x_7 + 5.21x_8 \\ & +0.21x_9 - 8.4x_{10} - 13.68x_{11} - 21.16x_{12} \\ & -208.01x_{13} - 13.36x_{14} + 16.2x_{15} \end{aligned} \tag{9}$$

Table 2 illustrates the weighting of all 15 variables for each objective function. The running bars indicate the high impact variables per objective function.

For each of the objective functions the key influencing variables are:

a *Economic function (CEI)*
- Efficient engines (x_{14}) results in optimum fuel consumption by fleet vehicles, hence fuel is a key contributor to operational costs.
- IoT (x_{13}) improves operations by transmitting and analysing data in real time, facilitating informed decision making.
- Streamlining inbound (x_1)/outbound (x_2) deliveries results in reduced movement and reduced logistics costs.
- Efficient operational practice (x_{15}) reduces costs of internal operations.

b *Environmental function (CEnI)*
- Efficient engines (x_{14}) result in optimum fuel consumption, reducing CO_2 emissions.
- Streamlining inbound deliveries (x_1)/outbound deliveries (x_2) reduces fuel consumptions and associated CO_2 emissions.
- Efficient operational practice (x_{15}), and automation (x_{12}) reduces resource utilisation, energy demand and emissions.

c *Social function (CSI)*
- IoT (x_{13}) results in systems integration and reduced personnel effort and hours.
- Streamlining of outbound deliveries (x_2)/inbound deliveries (x_1) results in reduced personnel effort and hours.
- Automation (x_{12}), and efficient operational practice (x_{15}), allows machines/systems to perform the activity of personnel, reducing personnel hours.

Based on the operational range of the 15 critical business variables, the maximum and minimum *CEI*, *CEnI*, *CSI* and *BSI*, is determined. The Taguchi L16 DOE protocol is applied in determining the range of the *CEI*, *CEnI*, *CSI* and *BSI*. It is a 15 factor, two level design, resulting in 16 unique experimental protocols (refer to Table 3), with 1 representing the minimum state of the variable and 2 the maximum state. For each run, the *CEI*, *CEnI*, *CSI* are calculated using equations (7) to (9), and the BSI is calculated as per equation (4).

This creates a second data matrix (16 × 5) of the individual objective functions and the associated BSI. This data matrix is used to refine the weights of the BSI equation [equation (4)]. Applying linear regression to the second data matrix, results in a corrected BSI equation as illustrated in equation (10).

$$BSI = -71.45 + 70.42\ CEI + 12.24\ CEnI + 90.68\ CSI \tag{10}$$

Table 2 Weighting of the 15 variables

Variable name	*Economic coefficients*	*Social coefficients*	*Environmental coefficients*
Planned inbound deliveries	48.55	7.96	18.14
Planned outbound deliveries	–32.36	–3.43	–35.62
Number of rail deliveries	0.77	0.60	–6.47
Number of RFPs processed	0.82	–0.01	0.90
Number of payable receipts received	2.47	0.04	8.50
Number of expense reimbursements	–0.12	0.00	–1.70
Number of suppliers	0.76	–0.03	6.27
Number of orders	1.77	0.04	5.21
Number of job requisitions	–0.74	–0.04	0.21
Number of HR development PR’s	–3.10	–0.05	–8.40
Number of payroll claims	–4.83	0.05	–13.68
Automation	7.56	2.60	–21.16
IoT	–52.28	0.46	–208.01
Efficient engines	–136.28	–23.68	–13.36
Efficient operational practice	–17.30	–4.49	16.20

Table 3 DOE protocol

Run number		*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*16*
Planned inbound deliveries	x_1	2	1	1	2	1	2	2	1	1	1	2	2	1	2	1	2
Planned outbound deliveries	x_2	2	2	1	1	1	1	2	1	2	2	2	2	2	1	1	1
Number of rail deliveries	x_3	1	2	1	2	1	2	1	1	2	2	1	1	2	2	1	2
Number of RFPs processed	x_4	1	1	1	1	1	2	1	2	2	1	2	2	2	1	2	2
Number of payable receipts received	x_5	2	1	1	2	1	1	2	2	2	1	1	1	2	2	2	1
No of expense reimbursements	x_6	2	2	1	1	1	2	2	2	1	2	1	1	1	1	2	2
Number of suppliers	x_7	1	2	1	2	1	1	1	2	1	2	2	2	1	2	2	1
Number of orders	x_8	2	1	2	1	1	1	1	2	1	2	1	2	2	2	1	2
Number of job requisitions	x_9	1	1	2	2	1	2	2	2	1	2	2	1	2	1	1	1
Number of HR development PR’s	x_{10}	1	2	2	1	1	1	2	2	2	1	2	1	1	2	1	2
Number of payroll claims	x_{11}	2	2	2	2	1	2	1	2	2	1	1	2	1	1	1	1
Automation	x_{12}	2	1	2	1	1	2	1	1	2	2	2	1	1	2	2	1
IoT	x_{13}	1	1	2	2	1	1	2	1	2	2	1	2	1	1	2	2
Efficient engines	x_{14}	1	2	2	1	1	2	2	1	1	1	1	2	2	2	2	1
Efficient operational practice	x_{15}	2	2	2	2	1	1	1	1	1	1	2	1	2	1	2	2

Equation (10) illustrates that for the logistics business the three factors are not equally weighted, as initially estimated in equation (4). The social and economic functions have a higher impact on the BSI. The high weighting of the social function illustrates limited automation of operations; the logistics business activities are primarily manually executed by personnel.

The reference BSI [as per equation (10)] and reference economic, environmental, and social functions are determined by setting the states of the 15 variables to the current operational set-point. Due to the inherent variability in operations, the current operational set-points are defined as the median values of the 2,400 Monte Carlo Simulations. The reference states are comparatively analysed against the respective minimum values. The target BSI are set lower than the reference state BSI, as lower operational costs, CO2 emissions and personal hours results in greater sustainability driven by increased profits, reduced environmental impacts and personnel focusing on cognitive tasks and continuous improvement.

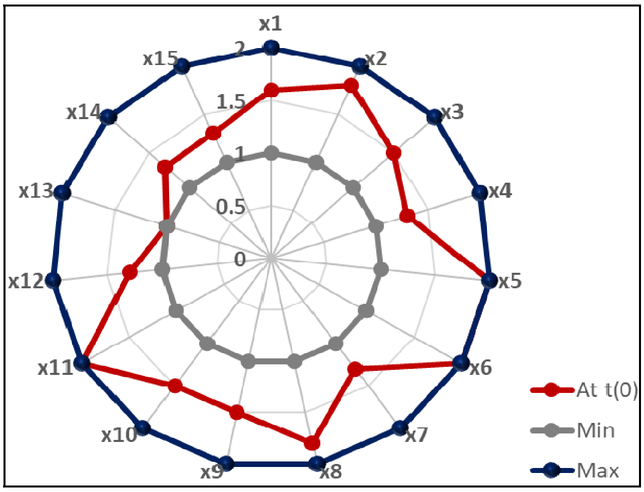
All the BSI factors have a significant potential for reduction (greater than 50%) to the respective minimum functional output value. The social function (personnel hours) has the greatest potential for reduction at 65.16%, which can be enabled via automation, and IoT.

The reference state (t_0) and the minimum and maximum state of the 15 variables are illustrated in Figure 3. Figure 3 illustrates that the operational variables (x_1 to x_{11}) have significant opportunity for optimisation to minimum operational state. Variables (x_{12} to x_{15}) are the optimisation options, which are currently at minimum application, with opportunity for wider application in the business.

Table 4 Reference BSI and objective function outputs at time $t_{(0)}$

	Reference functional output	*Minimum functional output*	*% change to min*	*Maximum functional output*	*% change to max*
BSI	242.95	108	55.55	269.12	9.72
CEI (million ZAR)	343.95	165.24	51.96	376.72	8.70
CEnI (kilotons)	43.78	21.66	50.52	58.41	25.05
CSI (thousand hours)	341.84	119.09	65.16	391.42	12.67

Figure 3 Reference state of variables at time $t_{(0)}$ (see online version for colours)



The model is now executed as per the reverse loop in Figure 2 to find the improved state at $t_{(1)}$. An optimised business state is sought at $t_{(1)}$, which is defined as a BSI lower than the reference state.

4.3 *Sustainability improvement potential*

The first step in the optimisation process is to define the improved BSI at a time $t_{(1)}$. The second step is the calculation of the optimised state of each objective function of $CEI_{t(1)}$, $CEnI_{t(1)}$ and $CSI_{t(1)}$, as per equation (10). The third step is the determination of the status of the 15 variables (x) to achieve the optimised $CEI_{t(1)}$, $CEnI_{t(1)}$ and $CSI_{t(1)}$.

The optimised BSI at $t_{(1)}$ is set at 8% lower than BSI at $t_{(0)}$ (SIP_1) and the BSI at $t_{(2)}$ is 14% lower than the BSI at $t_{(0)}$ (SIP_2). The corresponding states of the economic $\{CEI_{t(1)}, CEI_{t(2)}\}$, environmental $\{CEnI_{t(1)}, CEnI_{t(2)}\}$and social functions $\{CSI_{t(1)}, CSI_{t(2)}\}$ are calculated using Microsoft Excel, refer to Table 5.

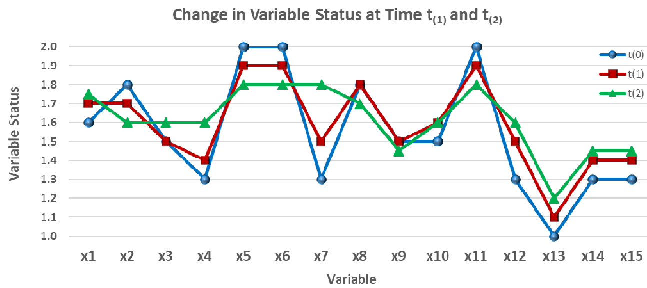
Table 5 Business opportunity to improve BSI

	Reference $t_{(0)}$	*Time* $t_{(1)}$	*% SIP*	*Time* $t_{(2)}$	*% SIP*
BSI	243	223	8.1	208	14.3
CEI (million ZAR)	344	317	*7.9*	299	*13.1*
CEnI (kilotons)	44	40	*7.8*	38	*12.4*
CSI (hours*10^3)	342	313	*8.5*	288	*15.7*

The results reveal that in order to achieve the targeted business sustainability $\{BSI_{t(1)}, BSI_{t(2)}\}$, the largest reduction is required by the social function $\{CSI_{t(1)}, CSI_{t(2)}\}$, followed by the economic function $\{CEI_{t(1)}, CEI_{t(2)}\}$, and lastly the environmental function $\{CEnI_{t(1)}, CEnI_{t(2)}\}$. This aligns to the BSI equation [equation (10)], which identifies the social function as the most significant, followed by the economic and environmental functions, respectively. The practical business benefits includes: 30,000 personnel hours at reduction at ($t_{(1)}$) and 53,000 personnel hours reduction at ($t_{(2)}$); 28 million rand (USD2 million) operational cost saving at ($t_{(1)}$) and 44 million rands (USD3.2 million) operational cost saving at ($t_{(2)}$) and 3 thousand tons CO_2 emissions reductions at ($t_{(1)}$) and 5 thousand tons CO_2 emissions reductions at ($t_{(2)}$). The reductions are achieved by optimising the 15 variables.

The state of the 15 variables at $t_{(1)} = \{(x_1)_{t(1)}, \ldots, (x_{15})_{t(1)}\}$ and at $t_{(2)} = \{(x_1)_{t(2)}, \ldots, (x_{15})_{t(2)}\}$ are calculated. The variables at t_0 (reference) and the two optimised states ($t_{(1)}$, $t_{(2)}$) are represented in Figure 4. For the coded values, 1 represents the minimum state and 2 the maximum state.

Figure 4 Status of the 15 variables for the improved BSI at $t_{(1)}$ and $t_{(2)}$ (see online version for colours)



For each of the objective functions the following variables, as quantified by the model, must be optimised:

- The number of inbound deliveries (x_1) need to be increased by between 2.17% and 3.26%
- The number of outbound deliveries (x_2) need to be reduced by 2.08% and 4.17%.
- Automation (x_{12}) needs to be achieved on strategic processes including navigation, and warehouse. The increased extent of application of automation should be between 15.4% and 28% for the identified processes.
- The extent of application of IoT (x_{13}) needs to increase between 10% and 20% for the identified systems.

- The deployment of efficient engines (x_{14}) to 33% to 50% of the current fleet.
- Efficient operational practice (x_{15}) improvement is identified, and 33% to 50% of this needs to be enacted.

It must be noted that the new sustainable business state is dependent on a complex set of inputs and not all variable changes are possible due to the business constraints. Thus, a contextualisation of the allowed variable changes, as verified by the logistics expert, provides the following insights for improved performance

- IoT (x_{13}), automation (x_{12}), and efficient operational practices (x_{15}) synchronises the warehouse, inbound and outbound delivery processes. Efficient operational practices include platooning and the use of low resistance tyres.
- Increase in the number of inbound deliveries (x_1), with a decrease in the outbound deliveries (x_2) due to smart route planning and traffic management systems, automatic guided vehicles, shelf moving robots and VANET. These results in reduced fuel consumption, fuel costs, CO_2 emissions, personnel hours, and extended life of fleet vehicles.
- New and increased business opportunities as the business is now capable of responding to a higher number of requests for proposals (x_4), increasing the number of inbound deliveries and associated revenue.
- Reduction in the number of payable receipts, expense reimbursements, general order purchases (miscellaneous items such as stationery) and payroll claims due to improved processes; utilisation of automation for repetitive and high-volume tasks and automatic in-system checks for errors. This results in cost savings, CO_2 emissions reduction and improved personnel hours utilisation (personnel can be assigned to more productive tasks such as support in development of proposals in response to request for proposals).

The simulation of improvements provides business decision makers with forecasting capacities based on potential investments. Decisions can be made based on the model outputs and impacts to the business. The model can be adopted according to the business TBL targets and the variables to be improved extracted from the model.

5 Conclusions

The key objective of this research is the development of a predictive model for business sustainability defined as TBL. Business sustainability is a key function in this technologically centric, digital world. The key to sustainability includes various complex decision-making options. The tools and models that provide decision support currently orientate around specific business functions or knowledge areas. This includes business sustainability modelling, with most research work providing a framework of sorts for business but none, holistically covering the entire business or with predictive capacities.

A model that facilitates decision making, prior to implementation of any sustainability intervention (technical, environmental, technological, or other), is developed and demonstrated. The model has significant predictive capacities and provides for interdependencies of all variables affecting the sustainability of a business. The optimisation loop of the model, as configured, has the capacity to identify the new states of the variables to achieve the improved BSI at a new time $t_{(x)}$.

The model is successfully demonstrated by application to a logistics business. Two optimised business states, with a SIP of 8% and 14% are defined for the logistics business. For the SIP of 8% and 14% the model forecasts 28 million rand (USD2 million) to 44 million rands (USD3.2 million) operational cost saving, 3 to 5 thousand tons CO_2 emissions reductions and 30 to 53 thousand man-hours reductions.

The inclusion of all functionalities provides for a powerful method in determining the future optimal BSI. The model potential and capacities are limitless as all variables influencing the business can be modelled, but the complexity is a constraint. The practical benefit of the model is that companies have a detailed forecasting tool to predict the impact of changes the company seeks to action. The simulation assists with decision making to strategies on best options on investment for improving the business.

The model is strategic and highly dependent on BPs, which forms the basis of this study. The primary limitation of the model is the accuracy of the BPs together with the resources declared as inputs. Future research work is to develop further accuracy around BPs for businesses. A secondary limitation of the model is the dependency on skills in BP science combined with simulation, which is not a common combination of skills. Future work to mitigate some of the challenges include an expansion of the BP database together with stronger expert vetting to reinforce model credibility and strengthen the repository for further modelling. Future work includes the integration of logistics with broader business models into value chain models.

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Appendix (see online version for colours)