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Optimising Resource Allocation in SMMEs: A Linear Programming Approach for SA Petro

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Abstract

This paper explores the application of linear programming (LP) as a strategic tool for enhancing profitability in SMMEs, explicitly focusing on SA Petro, a South African Johannesburg startup. The primary objective is to optimise SA Petro's deployment of its delivery resources to maximise their profit. Data was collected from SA Petro through interviews with the organisation's CEO, including company records and synthesised into information tables that informed the formulation of the LP model. The LP model was solved using QM for Windows. According to the optimal solution, SA Petro should deliver 150,000 litres of diesel by truck, 120,000 litres by train, and the remaining 730,000 litres by pipeline, yielding a projected profit of R555,000. Reviewing the sensitivity analysis, since all the logistics resources are still surplus at the given production level, the optimal strategy for SA Petro would be to accept more orders up to a feasible upper limit of 1,270,000 litres. This increase will enable the company to deploy the unused logistic resources. The study yields meaningful insights into the combination of product distribution options that will optimise operations for SA Petro.

Keywords
Linear programming, optimisation, South African Fuel industry, Small and Medium Enterprises

1. Introduction
Business process optimisation is crucial for an organisation to remain sustainable; it speaks not only to business survival but also to other facets of sustainability, such as environmental and social impact. Linear programming is one of several tools used for process optimisation. This tool, however, is handy because of its characteristics. A linear program has an objective function depicting what is desired, with constraints on the available resources, including the operating environment and defining decision variables. These characteristics speak to the general format of optimisation problems faced in any organisation (Nwobodo-Anyadiegwu 2023). Businesses, irrespective of whether it is manufacturing or service industry, usually have an objective such as maximising profits or minimising costs, and they need to figure out how to do that subject to the limitations found in their specific context (Syifa et al. 2023; Nwobodo-Anyadiegwu 2023).

With South Africa's rising unemployment rate, SMMEs (Small, Medium, and Micro Enterprises) must become more sustainable. They are one of the compelling forces combatting unemployment, contributing about 40% to the country's GDP (UNDP South Africa 2024). Linear programming, as mentioned, is well adapted to solving production problems. Additionally, to the benefit of SMMEs, LP can be applied to various problems across different sectors; for instance, it can be used to solve investment problems in the financial industry (Jain 2019). In the current study, LP was used to optimise operations in the energy sector, as we will see with SA Petro, a fuel wholesaler in Johannesburg, Gauteng, who wishes to determine the best way to deploy their delivery assets.

1.1. Objective

Statistics show that five out of seven small businesses fail within their first five years (primarily due to lack of access to resources) (Nyakaza 2024). It is common practice for startups to unnecessarily burn through large sums of revenue due to a lack of technical decision-making systems, as decision-making tools are deemed not a crucial investment. In this study, we examine whether LP can be used in SA Petro (an SMME environment) to determine the right combination of delivery methods to fulfil its forecasted demand. This study highlights the relevance of LP as a low-cost solution for making informed technical decisions and minimising business vulnerability to failure.

2. Literature review

Linear programming is a mathematical model that helps decision-makers realise their objectives, subject to constraints such as competing resources, like labour hours and raw materials (Render, et al., 2024; Heizer, et al., 2023). For a comprehensive understanding of the concepts in this paper, this Literature review will look at the definition, methods, applications, and history of linear programming. The term linear in the name alludes to the requirement that all functions be linear in the model (Taylor 2019). The model's equations include an objective function and linear constraints, expressed as equalities and inequalities (Nwobodo-Anyadiegwu 2023). Once an LP has been formulated, there are several means of solving it, the most rudimentary being the graphical method, which only applies to LPs with two decision variables; more complex LPs use the simplex method or modern computational software designed for LP (Hiller & Lieberman 2021).

Linear programming has numerous applications; for instance, it can maximise investment portfolio returns, minimise inefficiencies in a production process by prescribing the most efficient product mix or maximise the return on marketing investment (Taylor, 2019). For this reason, LP is applied in many sectors, such as healthcare, agriculture, mining, energy and transportation, to name a few (Akpan & Iwok 2016).

The first instances of something akin to linear programming being used were in the 1800s by Fourier Joseph (Oyekan & Temisan, 2019). Linear programming was first used in the 1930s by Leonid Kantorovich in Russia, but this was hidden away behind the Iron Curtain (Erickson 2019). A decade later, in the West, LP was rediscovered in the early 1940s by Tjalling Koopmans (Erickson 2019). In 1947, George Dantzig published the first coherent algorithm capable of solving linear programming problems (Oyekan & Temisan 2019). During World War II, as the need to optimise military logistics arose, LP became an essential tool for planning and decision-making. This wartime application opened the world to its utility (Dantzig 2002). As a result, LP is now applied across all disciplines to solve different kinds of problems.

Investigating the utility of Linear programming in SMMEs is not a new phenomenon. Nwobodo-Anyadiegwu (2023) conducted a study on Nayo, an Aluminium company in Enugu, Nigeria. The organisation was struggling with inventory management and breaking even. The study sought to establish an efficient production level for the Aluminium products Nayo was producing. Data on company records was collected from relevant personnel in the organisation, i.e. the CEO and the operations manager, informing the formulation of the LP (Nwobodo-Anyadiegwu, 2023). QM for Windows software was utilised to solve the LP. The study identified the organisation's inefficiencies, securing an additional income of 119720.00 Naira. Oyekan and Temisan (2019) conducted a similar study with Johnson Nig Ltd.'s Bakery division. The study sought to establish an ideal product mix for the bakery's different bread sizes. Still, unlike the Nayo case, this study was solved by utilising the simplex algorithm to obtain an optimal profit. Zakariyya et al. (2022) replicated the study with a different company in Nigeria and got similar results.

Jain (2019) conducted a study based on data provided by the Central Bank of India; the study aimed to determine how to best allocate 150 crores to different loan offerings of commercial banks to get the greatest return. The offerings were personal, car, home, agricultural, commercial, and education loans. The study also examined how to maximise investment returns for a senior citizen investing in the bank. Mustafa et al. (2021) developed a simplex problem to help a Software organisation determine the optimal mix of projects for their specific offerings. The purpose was to ensure the startup was profitable. Many South African SMMEs are yet to explore the process optimisation potentials of linear programming. Although extant literature on the application of LP in SMMEs exists, to the author's knowledge, there is a dearth of literature on the South African context. Hence, the current study hopes to grow this body of literature.

3. Methods

Information about the organisation's operations was gathered from the company CEO and other operatives. This data informed the formulation of the LP problem model; the assumptions of an LP (additivity, divisibility, and proportionality) were observed. We also assumed certainty, meaning the stated conditions will remain until otherwise indicated. A non-negativity constraint was also added to ensure that the decision variables would not take on negative values, as negative resources or products are not feasible. The resulting LP was put into QM for Windows for calculation. The resulting solution was analysed in the results section.

4. Data Collection

Several interviews with the organisation's CEO and operatives were set up and conducted over two weeks to collect the study data. In these interviews, information on the organisations' value chain was divulged. How each delivery method worked and affected the organisation was also disclosed. The collected data resulted in the case study below:

Case study

State of the market

The South African fuel market has had several significant events happening. Geopolitical conflicts, for instance, contribute to oil price volatility in the country (VOCFM 2024). On the other hand, the output capacity of refineries in South Africa continues to wane as refineries shut down, either because of accidents or organisations pulling out of South Africa due to increased business costs. The result is that South Africa has become increasingly dependent on imports to meet demand (News24 2023) (BusinessTech 2022).

In the wake of these disruptions, the petrochemical wholesale market is experiencing disruptions across its value chain in South Africa. The increased reliance on imports of oil products forces SA to increase the capacity to store fuel, and the necessity of a sudden change in investment focus has had adverse effects on the value chain of the petrochemical industry as a whole (News24, 2022). The volatility of oil prices from foreign suppliers has also caused oil and diesel prices to fluctuate in the country (VOCFM , 2024), which is quite a predicament as the South African economy is sensitive to oil price volatility. Consequently, it has become increasingly more challenging for wholesalers like SA Petro to do business. As a result, the effect is slimmer profit margins. "The market conditions are more favourable to established organisations in the industry; they have the assets to navigate the current turmoil. While I have seen many organisations like mine go out of business in the wake of the war between Russia and Ukraine," paraphrased the CEO of SA Petro.

SA Petro

SA Petro is an oil products wholesaler operating in Johannesburg, South Africa. The organisation's client list includes businesses in the agricultural and mining sector, specifically open-cast mines, as mines depend on oil products such as diesel. "Without diesel, nothing can happen in the mines," says the CEO of SA Petro. On average, the storage capacity for diesel used in mining operations can vary widely. Many mines utilise small storage tanks, typically ranging from 20,000 to 100,000 litres depending on their operational scale and regulations, the maximum being 1,000,000 litres for more extensive operations. According to the company CEO, for SA Petro's customers, delivery on schedule is a significant factor in meeting their business target. Hence, the company historically declines orders once they reach a threshold of 1 million litres for the fear of not meeting the customer demand timeously.

SA Petro uses different means to deliver its products to the mines, mainly trucks, trains, and pipelines. According to SA Petro, their trucks can carry up to 42,000 litres; train carriages can carry 60,000 litres, and they usually have a train with 10 carriages. Pipelines can transport up to 1,000,000 litres. Trucks take a maximum of 72 hours to deliver, trains take a maximum of a week, and pipelines take 2 weeks.

On average, the profits from truck deliveries are 30c per litre. The differences in earnings between train and pipeline deliveries are minor; train and pipeline profits are about 60c per litre. Since mines depend on oil products such as diesel, they usually give their suppliers a forecast of their needs. These forecasts are subject to occasional errors; in such cases, emergency deliveries are made to ensure that the mines do not run dry, and only trucks can be used for such orders, as they have the fastest turnaround. According to SA Petro's estimations, these account for 10-15% of the orders from the mines.Certain mines have heavily invested in railways, as it cuts the costs of products to be delivered by rail. These organisations prefer their orders to be delivered by rail; they account for 12% of SA Petro's orders. Open-cast mines consumption ranges from 200,000 to over 1 million litres monthly, depending on production levels and equipment used; this is broken down to approximately 40 deliveries per month.

As a startup in the Petrochemical industry in South Africa, SA Petro utilises 3rd party assets from established organisations such as Engen and Total to fulfil their orders. Theoretically, they can call on these on demand, but practically, there is a limit to the availability of these assets. SA Petro is not the only organisation that relies on these assets. SA Petro can use up to 10 trucks and 3 trains per week. Although pipelines can pump up to 1,000,000 litres, this capacity is shared with other organisations doing similar work. Thus, SA Petro has a finite number of orders it can place during the month, around 5 per month.Using the available historical data, SA Petro wishes to know how many litres of diesel it should deliver using Truck, Train and pipeline deliveries to maximise profit per client/account in December 2024. Table 1 presents a summary of data used for the LP model formulation.

Table 2. Summary of information used to formulate the LP

	Truck	Train	Pipeline
Profit per litre	30c	60c	60c
Capacity (litres)	1680000	7200000	1000000
Demand (litres)	150000	120000	***x***

Decision variables
X1= Litres delivered by truck
X2=Litres delivered by train
X3= Litres delivered by pipeline

4.1. Objective function

SA Petro wishes to know how many litres of diesel it should deliver using Truck, Train and pipeline deliveries to maximise profit. Truck deliveries earn the organisation 30c per litre, and each truck carries 42,000 litres. Train deliveries earn the organisation 60c per litre and can hold 600 000 litres. Pipeline deliveries earn about 60c per litre. A pipeline can theoretically deliver 1,000,000 litres. Hence, the objective function for the model is defined :
Maximize $Z = 0.3X_1 + 0.6X_2 + 0.6X_3$

4.2. Constraints

1. SA Petro has clients with varying monthly demands; for this study, we shall look at their demand of 1,000,000 Liters per month.

   X1+X2+X3= 1 000 000 litres

2. SA Petro has 40 truck deliveries at their disposal (10 trucks per week*4 weeks). Each truck can carry 42,000 litres per trip. This means 1 680 000 litres can be delivered by truck.

   X1<= 1 680 000 litres

3. SA Petro can make 12 deliveries by train this month (3 trains per week*4 weeks). Each train delivery has the potential to deliver 600,000 litres. 7 200 000 litres can be delivered by train.

   X2<= 7 200 000 litres

4. SA Petro can make 5 deliveries using pipelines this month. Pipelines have a capacity of 1,000,000 litres. And each delivery consumes a fraction of this capacity.
   X3<= 1 000 000 litres

5. 12% of the deliveries need to be made by rail

   X2>= 120 000 litres (0.12* 1 000 000)

6. 15% of the deliveries must be made by truck.

   X1>=150 000 litres (0.15*1 000 000)

7. Non-negativity constraint

   X1, X2, X3 >= 0

SA Petro Linear program model:

Maximize Z=0.3X1 + 0.6X2 + 0.6X3

Subject to

1. $X_1 + X_2 + X_3 = 1\ 000\ 000$
2. $X_1 <= 1\ 680\ 000$
3. $X_2 <= 7\ 200\ 000$
4. $X_3 <= 1\ 000\ 000$
5. $X_2 >= 120\ 000$
6. $X_1 >= 150\ 000$

$X_1, X_2, X_3 >= 0$

5. Results and discussion

According to the optimal solution of the relaxed LP seen in Table 5, SA Petro should commit to delivering 150 000 litres of diesel using trucks; they should deliver 120 000 litres of diesel using trains, then they should meet the remaining demand, which is 730 000 litres using pipelines, with this combination they are projected to realise a profit of R555 000.

Notably, suppose the optimal relaxed solution of an LP contains fractional values. In that case, it is recommended that an all-integer solution be obtained since the fractional values do not yield any real profit (Nwobodo-Anyadiegwu, 2023). In the case of SA Petro's LP, there is no need to add integer restrictions as the optimal solution values are all integers (see Table 5). Hence, the all-integer LP solution would be the same as the relaxed solution, as seen in Table 3.

Since all the logistics resources are still in surplus at the given production level (see the sensitivity analysis in Table 4), their marginal value is zero. SA Petro could increase demand by accepting more orders within a feasible upper limit of 1 270 000 litres (270 000<= Q1<= 1 270 000); by using more left-over resources, the company can make more profit without increasing the cost relatively.

While the LP provides an optimal solution under the given conditions, should the cost of fuel increase, for instance, to a point where SA Petro's profit using trucks surpasses 60c per litre, the solution would become obsolete. This outcome infers that the solution is only feasible if the real-world conditions of the problem stay within the bounds expressed in the sensitivity analysis (see Table 4). Any changes beyond this limit would require a new LP model for SA Petro. Table 2 depicts the iterations from the QM for Windows output, starting from the initial table to the optimal. Table 3 is the integer programming output. Table 4 typifies the sensitivity analysis for products and constraining resources or conditions. Finally, Table 5 is a summary of the optimal solution.

Table 3. Illustration of the problem in QM for Windows.

Iterations Cj	Basic Variables	Quantity	0.30	0.60	0.60	0artfcl 1	0slack 2	0slack 3	0slack 4	0artfcl 5	0surplus 5	0artfcl 6	0surplus 6
Phase 1-iteration 1													
1	artfcl 1	1 000 000	1	1	1	1	0	0	0	0	0	0	0
0	slack 2	1 680 000	1	0	0	0	1	0	0	0	0	0	0
0	slack 3	7 200 000	0	1	0	0	0	1	0	0	0	0	0
0	slack 4	1 000 000	0	0	1	0	0	0	1	0	0	0	0
1	artfcl 5	120 000	0	1	0	0	0	0	0	1	-1	0	0
1	artfcl 6	150 000	1	0	0	0	0	0	0	0	0	1	-1
	zj	1 270 000	-2	-2	-1	1	0	0	0	1	1	1	1
	cj-zj		2	2	1	0	0	0	0	0	-1	0	-1
Iteration 2													
1	artfcl 1	850 000	0	1	1	1	0	0	0	0	0	-1	1
0	slack 2	1 530 000	0	0	0	0	1	0	0	0	0	-1	1
0	slack 3	7 200 000	0	1	0	0	0	1	0	0	0	0	0
0	slack 4	1 000 000	0	0	1	0	0	0	1	0	0	0	0
1	artfcl 5	120 000	0	1	0	0	0	0	0	1	-1	0	0
0	X1	150 000	1	0	0	0	0	0	0	0	0	1	-1
	zj	970 000	0	-2	-1	1	0	0	0	1	1	3	-1
	cj-zj		0	2	1	0	0	0	0	0	-1	-2	1
Iteration 3													
1	artfcl 1	730 000	0	0	1	1	0	0	0	-1	1	-1	1
0	slack 2	1 530 000	0	0	0	0	1	0	0	0	0	-1	1
0	slack 3	7 080 000	0	0	0	0	0	1	0	-1	1	0	0
0	slack 4	1 000 000	0	0	1	0	0	0	1	0	0	0	0
0	X2	120 000	0	1	0	0	0	0	0	1	-1	0	0
0	X1	150 000	1	0	0	0	0	0	0	0	0	1	-1
	zj	730 000	0	0	-1	1	0	0	0	3	-1	3	-1
	cj-zj		0	0	1	0	0	0	0	-2	1	-2	1
Iteration 4													
0	X3	730 000	0	0	1	1	0	0	0	-1	1	-1	1
0	slack 2	1 530 000	0	0	0	0	1	0	0	0	0	-1	1
0	slack 3	7 080 000	0	0	0	0	0	1	0	-1	1	0	0
0	slack 4	270 000	0	0	0	-1	0	0	1	1	-1	1	-1
0	X2	120 000	0	1	0	0	0	0	0	1	-1	0	0
0	X1	150 000	1	0	0	0	0	0	0	0	0	1	-1
	zj	0	0	0	0	2	0	0	0	2	0	2	0
	cj-zj		0	0	0	-1	0	0	0	-1	0	-1	0
Phase 2													
,6	X3	730 000	0	0	1	1	0	0	0	-1	1	-1	1
0	slack 2	1 530 000	0	0	0	0	1	0	0	0	0	-1	1
0	slack 3	7 080 000	0	0	0	0	0	1	0	-1	1	0	0
0	slack 4	270 000	0	0	0	-1	0	0	1	1	-1	1	-1
,6	X2	120 000	0	1	0	0	0	0	0	1	-1	0	0
,3	X1	150 000	1	0	0	0	0	0	0	0	0	1	-1
	zj	555 000	,3	,6	,6	,6	0	0	0	0	0	-,3	,3
	cj-zj		0	0	0	-0,6	0	0	0	0	0	0,3	-0,3

Table 4. Integer Programming Iteration Results from QM Windows

Iteration	level	Added constraint	Solution type	Solution value	X_1	X_2	X_3
			Optimal	555000	150000	120000	730000
1	0		INTEGER	555000	150000	120000	730000

Table 5. Sensitivity analysis

Variable	Value	Reduced Cost	Original Val	Lower Bound	Upper Bound
X1	150000	0	,3	-Infinity	,6
X2	120000	0	,6	-Infinity	,6
X3	730000	0	,6	,6	Infinity
	Dual Value	Slack/Surplus	Original Val	Lower Bound	Upper Bound
Constraint 1	,6	0	1000000	270000	1270000
Constraint 2	0	1530000	1680000	150000	Infinity
Constraint 3	0	7080000	7200000	120000	Infinity
Constraint 4	0	270000	1000000	730000	Infinity
Constraint 5	0	0	120000	0	850000
Constraint 6	-,3	0	150000	0	880000

Table 6. Linear Programming Results

	X1	X2	X3		RHS	Dual
Maximise	,3	,6	,6			
Constraint 1	1	1	1	=	1000000	,6
Constraint 2	1	0	0	<=	1680000	0
Constraint 3	0	1	0	<=	7200000	0
Constraint 4	0	0	1	<=	1000000	0
Constraint 5	0	1	0	>=	120000	0
Constraint 6	1	0	0	>=	150000	-,3
Solution->	150000	120000	730000		555000	

Limitations

The data for this study was obtained via interviews and company records. The interviews exposed the study to subjectivity, which may impair data accuracy. The study also assumes that the market environment is constant without considering the effect on market conditions or cost. A fuzzy goal LP or a stochastic LP is recommended for further studies.

6. Conclusion

This study shows the practical application of linear programming as an effective economic decision-making tool for process optimisation in SMMEs like SA Petro. Evidently, with more operational constraints and decision variables, an optimal production mix can be obtained at any time by applying the techniques used in this study. By optimising delivery resource allocation through the LP model, SA Petro can maximise profits while meeting operational constraints. The solutions produced by QM for Windows software indicate that SA Petro should deliver 150 000 litres via trucks, 120 000 litres by train and 730 000 litres through the pipelines. This will result in a profit of R555 000 for the month of December 2024. These results underscore the potential of LP to drive strategic decision-making in resource-constrained environments. Using such tools, SMMEs can improve their operational efficiency and secure long-term sustainability.

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Biograpies

Zeniphile Tebogo Gumede recently obtained his diploma in Operations management at the University of Johannesburg in 2024. During his academic career, he developed a strong interest in linear programming and its practical use in decision-making. His post-diploma scholarly focus reflects a commitment to broadening his understanding of applied Operations Research as an area of specialisation.

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