

Review Article

# Linear Programming at the Crossroads: Reviewing Traditional Applications and Exploring Future Potential in Sustainable Development and Digital Transformation

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**Abstract:** Linear Programming (LP) is an effective method that has been developing with time as a means of providing more efficient solutions to various optimization problems and decisions under difficult circumstances. It started as a way of planning production, transport, and resource utilization, but sustainability, digital revolution, and management by data has taken its relevance to the crossroad. The study explored the value of use of LP in the contemporary world, how it is better off with new technologies, and what it could be in the future. The paper employed the desk review research technique, relying on scholarly articles, books, and research reports to follow the development of LP since its conventional application in manufacturing and energy systems to new ones in artificial intelligence, smart cities, and environmental planning. The findings revealed that LP is highly suitable in terms of saving costs, improving efficiency and sustainable development. However, it still is problematic in the sense that it is founded on simple and a priori assumptions that is not always a reflection of reality. The authors concluded that with the addition of machine learning, cloud computing, and quantum optimization, such limitations would be minimized when using LP. LP would remain significant in making intelligent, sustainable, and data-informed decisions in future.

**Keywords:** Linear programming, Optimization, Digital transformation, Sustainability, Decision-Making.

## 1.1 INTRODUCTION

Since its formal introduction in the mid 20<sup>th</sup> century, Linear Programming (LP) has been a mainstay of optimization theory. Its root lies in the pioneering efforts of George B. Dantzig in World War II, when the problem of logistics, resource-allocation, and transportation that are part of military supply chains were solved using LP. Early methods such as the simplex method offered tools to solve linear inequalities and linear objective functions which are to be maximized or minimized under some constraint. LP later found its application in economics, forestry, manufacturing, and operations research, in which the resources were scarce, and systematic decision tools were needed. These new basics positioned LP as a mathematical novelty and an instrument useful to scientists, planners, and managers (Idisi & Ogumeyo, 2024).

Historically, the largest application of LP was in manufacturing, transportation, agriculture, and energy industries. It's utility to determine the optimal production schedule, supply chain management, land use allocation, and resource allocation design has left lasting influences. Subsequently, mixed-integer linear programming (MILP) and multi-objective LP (MOLP) also emerged to deal with integer decision variables or competing goals, like cost against environmental issue. In the energy domain, for example, MILP models have been extensively used to optimize power systems balancing efficiency, reliability, and the environment (Miehling *et al.*, 2023). The classical LP toolbox has therefore been enriched with non-linearities, discrete variables, and environmental factors without abandoning linear formulations when feasible.

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Over time, the application of LP in digitalization and sustainable development has gained popularity increasingly. For instance, an e-commerce fresh-food delivery system has been improved using a mixed-integer LP model with respect to costs, food wastage, and carbon footprint to assist in circular economy goals (Zhang *et al.*, 2025). In the same vein, an LP model application in consumer buying choices revealed how slight changes in favour of more sustainable products can achieve very significant environmental savings at a small additional cost (Sapan & Paç, 2024). In public health, a scoping review illustrated the use of LP to create food-nutrient-based nutrition guidelines for children aged five years and below, maximizing nutrient adequacy while keeping costs affordable (Miow *et al.*, 2025). These examples demonstrate how LP is being reinvented to solve today's problems, where economic efficiency is no longer more paramount than other goals, such as sustainability, and social well-being.

Linear Programming is therefore, currently at a crossroad. It has a solid foundation in its very history and practice that is proven; it is scalable due to the advancements in computing; and the necessity to maintain the long-term growth and digitalize the world requires new and cross-disciplinary solutions. This article chronicles a map of where LP has been, where its limits are today, and how changes in technology and sustainability makes it a needed tool in as far as the intricate international issues are concerned.

## 1.2 Statement of the Problem

Linear Programming (LP) has been established to be a potent optimization model to solve complex decision-making problems in resource allocation, production and energy system and supply chain management. The approach, although proven to be quite effective, is mainly based on the rigid assumptions, linearity and deterministic models that might not be able to reflect the complexity and uncertainty of the modern economic, environmental and technological scenarios. As the world is becoming digital, Industry 4.0 technologies and the need to pursue sustainable development are increasing, the question of whether the field of LP in its paradigm will be enough to support the decision-making needs of the future arises. It is highlighted in recent literature that classical LP models should be adapted in order to deal with uncertainty, risk and non-linearity in a more efficient way (Busing *et al.*, 2025). On the same note, scholars have observed that the future of eco-economic trade-offs in integration with information technology and sustainable technology requires the implementation of the LP to enable the use of data to make decisions (Zhang *et al.*, 2025). The difficulty is then to critically review the topicality of LP, see chances of integrating it with the new technologies, and overcome its shortcomings so that it could be used further in the development of sustainable and information-driven solutions.

## 1.3 Objective

The objective of the study is to critically assess the applicability of linear programming (LP) by examining its enduring relevance in classic and modern decision-making contexts while exploring its future potential through integration with digital transformation, and at the same time interrogating its limitations related to static assumptions, linearity, and uncertainty in order to propose pathways for extending LP beyond its conventional boundaries.

## 1.4 METHODOLOGY

The study explored the desk review methodology, which is based on information in past academic and professional literature. The comments in the review were grounded on the peer-reviewed journal articles, conference reports, books, and reliable reports. This was done considering the objective of the paper, which was to critically examine how the linear programming (LP) had been developed since the earliest application in the planning of production, resource allocation and optimization of the supply chains to more recent application in sustainability and digitalisation. The desk review was especially useful in this study because it provided the researchers with a chance to integrate diverse views and emphasize the manner of developing knowledge (Snyder, 2019; Xiao & Watson, 2019).

The materials were screened based on its relevance, presenting the research on the persistence of classical applications of LP or their effects regarding the resolution of the issues of sustainable development, energy systems, and digital technologies. The literature were analyzed in accordance with the classical application of thematic analysis, its emerging tendencies, and the perspectives. This type of a systematic review provided a reasonable perspective of the past and the present, and a pointer to the future (Paul & Criado, 2020; Kraus *et al.*, 2022). Desk review process was therefore appropriate in this study since it enabled the combination of various opinions, discovery of knowledge gaps, and expression of the subsequent phase in carrying out studies without the limitation of empirical field research.

## 2.1 Theoretical Framework

The Decision Theory formed the basis of this study. The history of the Decision Theory can be traced to Blaise Pascal in the 17th century and was further developed by Daniel Bernoulli in 1738 by the Expected Utility Hypothesis. John von Neumann and Oskar Morgenstern formalised it in 1944 in their Theory of Games and Economic Behavior, which developed the expected utility framework as a rational choice theory. Decision Theory presupposes that the decision-makers are rational, their preferences are consistent, and they attempt to maximize the results using scarce resources and information.

The theory has been extensively accepted in the fields of economics, management science and operations research. Its practical use was advocated by such scholars as Raiffa (1968) in organizing complex decisions under uncertainty, and criticized by March (1994) in the sense that decisions in reality are usually constrained by cognitive and organizational factors. Regardless of these criticisms, Decision Theory still forms the center of the explanation, as well as the enhancement of the optimization process, in particular, where there is a need to balance efficiency, risk, and sustainability in the decisions made. These two facets of thinking, its virtues and its drawbacks, make it even more valid as a model on the study of LP which succeeds in a setting that demands rigorous assessment of options and trade-offs. The theory explains the use of Linear Programming (LP) in making decisions in both developed and emerging areas of sustainability development and digital transformation. The most important concepts of Decision Theory can be seen in LP because it provides a framework of making rational decisions under the conditions of constraints, trade-offs, and multiple goals.

The decision theory is especially applicable to this study as it offers a rational perspective of studying the evolution of the LP as a tool that was previously applied in production, transportation, and resource distribution to the present one related to the idea of sustainability-oriented planning and digital ecosystems. By placing LP in rational decision-making, the theory highlights the reason why it is a potent decision-support tool in directing complex trade-offs in the development and technology-driven transformations. It emphasizes the ability of LP to improve the quality of decisions, efficiency, and innovation in situations whereby optimization and ethical responsibility are important towards long-term prosperity. In this way, the Decision Theory presents a strong basis of seeing the long-term validity and prospective of LP in tackling the current global issues.

## **2.2 Empirical Review**

The use of Linear Programming (LP) in solving decision making problems in business, industry and public systems is not a new concept. It has also been found to be particularly handy, as it provides step by step solutions, which are simple to follow, and even when dealing with extremely large problems. Research indicates that LP remains significant in the conventional fields like production planning, energy systems, supply chains and others.

### **2.2.1 Linear Programming in Production Scheduling**

Although linear programming (LP) is a long-established method for determining production timing and planning, it continues to be a valuable tool in modern manufacturing systems. Conventionally, LP has been used in the medium to long term production planning, as it assists managers to identify the most suitable schedules to direct resource use, lot-sizing, and meeting demands. Empirical research proves that when integrated with forecasts and uncertainty parameters, LP models produce accurate and consistent schedules that minimize disruptions in the operations of industries, including semiconductor manufacturing (Ziarnetzky *et al.*, 2018; Lin & Uzsoy, 2016).

In process industries, there is also research data that, incorporation of LP in rolling-horizon planning that requires schedules to be updated periodically to incorporate new information, leads to better overall performance. These strategies have been identified to improve resource use and throughput given that rescheduling policies are formulated cautiously to prevent instability and huge plan alterations (Stevenson *et al.*, 2020). These results point to the fact that LP not only ensures efficiency, but also provides the ground of flexible decisions in complex environments.

The availability of Industry 4.0 technologies has taken even the role of LP in reference to scheduling even further. Other tools such as digital twins, IoT sensors, and cloud platforms have become an augment to LP because they allow obtaining real-time information and immediately react to unexpected situations. In this setup, the digital tools can assist the factories to adapt rapidly when disruptions manifest themselves, and LP plans are sure at the base (which makes it reliable), and digital tools plans (which incite agility) ought to be combined (Mourtzis, 2022). In this context, digital tools enable factories to respond rapidly to disruptions, while LP-based plans provide a stable and reliable foundation. Therefore, integrating the robustness of LP planning with the agility offered by digital tools is essential (Mourtzis, 2022). The combination of LP with the digital twin system of scheduling has proven to be more efficient in production, reduce the lead times, and optimize machines utilization in practice in the industries (Grznar *et al.*, 2025).

Taken together, these research findings suggest that LP plays a crucial role in production planning, not only that includes conventional approach to planning, but is also an important component of the adaptable and data-driven manufacturing systems. Such a dual role highlights why LP remains the most actively used tool in practice despite the development of more modernized heuristic and AI-supported scheduling methods and thus represents a transition between classical optimization and digitally-enabled and future-oriented more comprehensive decision-making.

### **2.2.2 Linear Programming in Resource Allocation**

Historically, linear programming (LP) has been described as one of the most effective instruments in resource allocation so that limited resources are allocated in a manner that results in the maximum amount of efficiency or profit and the minimum possible cost. It was initially used in solving allocation problems in agriculture and military logistics,

whereby a decision on the allocation of land, labor or materials needed to be made under rigid conditions (Dantzig, 1963). The application of this foundation in modern applications has been spread to various fields including health care, learning and dissemination of services to the people. As a case in point, the allocation of scarce medical resources in the face of crisis such as hospital beds and ventilators during the COVID-19 pandemic were done using LP with better patient outcomes compared to ad hoc methods of allocation (Shah *et al.*, 2021). These works confirm the timeless relevance of LP in cases of limited resources and conflicting priorities.

Other than crisis management, LP has also found its way into the agricultural and manufacturing sectors, to better utilize inputs such as fertilizer, labor and raw materials. Empirical data shows that the LP-based farm planning models allow farmers to optimize land utilization and crop choices to grow the yields at reduced expenses (Fadare *et al.*, 2020). In industrial scenarios, allocation models enhance the distribution of machine time, employee placement as well as capital investments particularly in the event of uncertainty. As an example, idle time are reduced and productivity are decreased with the use of LP in the context of workforce allocation in case studies of manufacturing plants (Olabisi, 2019). These results demonstrate the broad flexibility of LP to small and large-scale resource allocation choices.

In the modern digital world, the application of LP in the process of resource allocation is augmented by the integration with data-driven and simulation based systems. For instance, the integration of LP with big data analytics and decision support platforms enable governments and organizations to distribute resources in a more dynamic and fair way (Shah *et al.*, 2021). In addition, the ever-expanding focus by increased number of organizations on the concept of sustainability leads to the LP models, being designed to distribute not only financial and physical resources but also carbon resources and energy credits (Kumar & Sah, 2022). This expansion explains why the traditional aspect of LP in the allocation of sources has continued to be refined and it is still a very important linking point between the classical approach of optimization and the decision making today that is necessitated by sustainability.

### **2.2.3 Linear Programming in Supply Chain Management**

Another classical area that linear programming has been involved indispensably is supply chain management (SCM), especially in optimization of logistics, inventory management and distribution networks. As a problem solver, traditionally, LP was used on the transportation problem, a typical formulation that attempts to minimize the cost of transporting goods between suppliers and consumers in the presence of demand and capacity constraints (Hitchcock, 1941). The simple model has been developed over a period into more sophisticated formulae that deals with the multi-echelon distribution, production-inventory trade-offs and just-in-time delivery. Empirical research studies on the subject in the recent past indicate that LP continues to be a key instrument in ensuring efficiency in the supply chain operations. For example, an optimization model based on LP implemented at a consumer goods organization lowered the overall distribution expenses by almost 15 percent without impacting the service levels (Alkahtani & Tiwari, 2021).

LP models have also been useful in inventory planning especially in those industries that deal with perishable goods or fluctuating demand. Empirical evidence indicates that LP has the ability to reduce holding and shortage costs through finding best reorder points and lot sizes, as opposed to traditional heuristic methods (Sharda & Akiya, 2022). In globalized supply chains, LP assists in equalizing the cost, lead time and risk through integrating various decision levels, including supplier selection, order assignment and choice of the method of transportation. Case studies have been used to illustrate that companies implementing the use of LP-based optimization of supply chains attain quantifiable increases in reliability of services and cost-effective operations in contrast to companies using experience-based planning only (Wang *et al.*, 2023).

In more recent times, LP in supply chain management has been intertwined with digital solutions of blockchain, IoT, and cloud computing. Such integrations enable the LP models to be dynamic in real-time when the inventory levels, transport delays or customer demand are altered. For example, LP models that run on blockchain have been employed to secure price transparency and mitigate fraud in supply chains and still attain optimal distribution costs (Zhang & Lee, 2022). As the concept of sustainability turns into the primary focus, the environmental goals, including reducing carbon emissions in addition to cost, have been integrated into the models of green supply chains based on LP (Boukherroub *et al.*, 2017). The developments prove that LP remains an essential part of SCM, a concept that develops into a complex framework that allows balancing efficiency, transparency, and sustainability.

### **2.2.4 Linear Programming in Energy Systems**

One of the most lasting and influential domains of application of LP is energy systems. In power systems, historically, generation and dispatch problems were solved with the help of LP, in which the aim was to allocate production to several generating units to satisfy demand at minimum possible cost (Dantzig, 1963). LP has over the years been generalized to multi-period planning, e.g. capacity expansion and fuel mix optimization. Empirical research indicates that the LP-based methods are still applicable when energy systems become more complex. A systematic review by Yu *et al.*,

(2023) established that in capacity-expansion planning, LP and linearized models are considered as the most significant, due to their scalability and computation capability.

Applications of LP in operational problems in conventional and renewable-based power systems have included unit commitment and dispatch problems. Based on empirical research of power grid operators, it has been shown that both the LP and mixed-integer LP model can be applied to plan generation resources and solve ramping limits and predict uncertainty (Reddy & Anbumozhi, 2021). Furthermore, the use of LP in the electricity markets is broad because it can be used to determine the optimal bidding methods, and to emulate transmission limitations in day-ahead markets. It has been found out that the models facilitate the minimization of costs and grids stability, which demonstrates the significance of LP in ensuring the reliability of energy supply (Conejo *et al.*, 2018).

Renewable energy planning and sustainability objectives are increasingly becoming allied with LP these days. An illustration of this is the optimization of the integration of wind and solar energy in a grid at the lowest cost, storage capacity and emission reduction through the use of LP models (Yu *et al.*, 2023). Another manifestation of the versatility of the technology at the decarbonization times is the integration of the LP with smart grid technologies, demand response systems and energy storage optimization. Thus, LP is not only a traditional way to cut costs but a modern conductor of sustainable energy transformation. That is why it is relevant in different spheres of life (Yu *et al.*, 2023).

### **2.2.5 Linear Programming in Machine Learning Hybrid**

Another obvious trend in recent research is the combination of Linear Programming (LP) with machine learning to solve the challenges of scale, uncertainty, and real-time decisions. Li *et al.*, (2023) developed a hybrid system of scheduling, where machine learning preliminary solutions to flexible job-shop models were initially produced, and then optimized by Mixed-Integer Linear Programming (MILP) models to enhance accuracy. Their findings revealed that they (ie Machine Learning Hybrid and MILP) not only made decisions faster but also improved efficiency and sustainability than when one of the methods is used alone. Similarly, Ouhadi *et al.*, (2024) conducted a review of the increasingly popular use of machine learning in operations research, and particularly in scheduling. They discovered that the combination of machine learning and MILP is beneficial, as it enhances the accuracy of prediction, accelerates calculation, and heuristics that are applied in solving problems.

More recently, a study by Li *et al.*, (2025) addressed one of the largest critiques of LP and MILP, which is that they are not easy to scale up to very large problems. They proposed a model-reduction method of machine learning in which smaller, simplified MILP models were produced by machine learning and could be solved significantly faster and provided near-optimal and interpretable answers. These studies collectively point to the direction that LP is shifting beyond its conventional boundaries. Using a combination of predictive ability of machine learning, with the structured optimization of LP, today's complex real-life scenarios are efficiently taken care of.

### **2.2.6 Linear Programming in Transportation, Logistics, and Transportation Scheduling (People and Goods)**

Linear Programming (LP) and Mixed-Integer Linear Programming (MILP) are highly applicable in transportation and logistics, particularly in balancing cost and environmental impact. Shoukat (2021) used MILP to freight transport in Pakistan and discovered that inter-modal transport (applying more than one mode such as rail and road) can save money and decrease carbon dioxide emissions relative to the use of trucks. Similarly, studies on multi-objective fleet scheduling by Su *et al.*, (2025) integrated various transport modes and took into account such aspects as traffic congestion, demand, and emissions. They had a superior fleet use as demonstrated in their model, reduced delays, and reduced costs with more sustainability.

There is also an interest among the researchers on how to manage uncertainty in transportation planning. To address the uncertain supply and demand in distribution issues, Joshi *et al.*, (2024) created a stochastic LP model. Their method balances various objectives e.g. cost, time and reliability by transforming uncertain variables into solvable models. Similarly, Majbah-Uddin and Huynh (2024) developed a disruption-resilient routing model of freight networks. Their stochastic MILP assists logistics managers to plan paths, which remain dependable in case of the failure of some connections or terminals.

There is also another significant direction of work that examines how trucks, buses, and even drones should be scheduled so that they can transport people and goods. Wang *et al.*, (2024) developed a Truck Appointment System, with the help of which the order of third-party trucks carrying finished products is arranged with the help of the LP models. This eliminates all queuing, idle capacity and increases the efficiency of transport. More futuristic models are combining traditional and emerging modes of delivery. Su *et al.*, (2025), suggested a MILP model, which combines the scheduling of buses and drones in their last-mile deliveries. Their findings indicate that the inclusion of drones in multi-modality systems can save money and enhance the speed of delivery relative to the situation where each mode is applied in isolation.

### 2.2.7 Linear Programming in Finance and Investments

Linear Programming (LP) has remained handy in the past few years in the area of portfolio management, particularly when investors have desires of balancing risk and returns within constraints of the real world. Grechuk and Hao (2022) demonstrated that risk budgets or any comparable constraint can be shared among investors, and efficient solutions can be obtained. On the same note, Cao (2022) compared the linear and quadratic programming in asset allocation and revealed that LP is useful utilizing simpler assumptions, and, hence, it is a viable option in some specific investment scenarios.

In portfolio management, conventional models tend to work poorly when there is uncertainty in estimating returns and risks resulting in making poor investment decisions. This was addressed by Kovalenko *et al.*, (2025), through the use of robust optimization techniques, which are based on LP. Their strategy renders the portfolios less prone to mistakes in forecasts, which means that the investment strategies are dependable even in unfavorable circumstances.

Researchers have also extended the LP models further to suggest how investors and regulators are viewing the performance and risk. Hu *et al.*, (2021) added performance attribution constraints in the portfolio optimization which allows managers not only to target performance and returns but also determine their origin. Ogboi *et al.*, (2025) demonstrate that both investment and loan portfolios can be analyzed using LP model, with a tool, like excel solver. They opine that LP is a useful and convenient tool of maximizing returns and dealing with risks.

### 2.2.8 Linear Programming in Agriculture, Farm Management, Health Care and Medicine

Linear Programming (LP) has continued to play an important role in the agricultural industry as it helps farmers to agree on their crops, irrigation processes, and resource assignment. Specifically, Boninsenha (2022) created a model of LP to optimize the utilization of water within the agricultural systems in a manner that allows farmers to maximize the utilization of land resources, labor, and water resources to maximize the yields and profitability. Similarly, Debnath *et al.*, (2024) used an LP-based approach to optimize the crop planning in the winter fallow period and demonstrated that crop planning models can assist in sustaining incomes and protecting against the rain variability. These studies report that LP provides simple to comprehend reasoned suggestions, regarding what farmers and policy makers ought to do.

The use of LP and Mixed-Integer Linear Programming (MILP) are used simultaneously to maximize various tasks in more complex farm systems which involve crops and livestock. An example of this is the MILP framework that was proposed by Gong (2025) which combined crop planning and dairy feed formulation where the managers can enhance profitability and minimize environmental consequences. Decision-makers can use such models to simulate the impact of hypothetical changes, like alterations in the amount of fertilizer used or the composition of feed, without making the problem too heavy to compute. This renders both LP and MILP useful instruments to agronomists and farm advisors who require realistic methods as opposed to idealistic models.

Other health care and medical applications of LP include the popular use of the model in the staff scheduling, management of patient flow, and allocation of resources. Nabavizadeh (2024) designed a MILP model to plan home health care in the context of the COVID-19 pandemic, enabling the providers to plan the assignment of nurses in the most efficient way, reducing the time spent on traveling to the location and minimizing the risk of being infected. Similarly, MILP was used in the maximization of staffing at hospitals, scheduling of the patients, reduction of waiting time and making the service more acceptable (Yinusa *et al.*, 2023). In the same vein, Fattahi *et al.*, (2022), employed LP to integrate patient transfer and resource planning and proved it can help hospitals to be more efficient in responding to the unpredictable inflow of patients. These applications demonstrate that the LP remains highly applicable to solve real-life problems where efficiency and reliability are considered to be paramount factors.

### 2.2.9 Linear Programming in Telecommunication Networks

Linear Programming (LP) is a good mathematical model applied in the process of solving many problems in telecommunication networks, such as cost reduction, network performance and the use of limited resources. LP and other versions of it, including the Integer Linear Programming (ILP) and the Mixed-Integer Linear Programming (MILP), provide an engineer with a chance to model such network targets and constraints in a logical way and find the most optimal solutions. LP models prove effective in planning, and the management of 5G and beyond networks owing to their simplicity and flexibility and compatibility with the conventional optimization tools (Ejaz & Choudhury, 2025).

In real telecommunication networks, LP is usually used in the process of path routing, resources allocation and virtual network slice design. MILP has been used by scholars in 5G transport systems, to locate network functions and direct data without too much delay and network intersection (Klinkowski, 2024). The minimization of energy use and improvement of performance in open radio access network (O-RAN) have also been modeled using Integer Linear Programming (ILP) where it was revealed that LP is convenient in the realization of a balance between performance and cost (Quarm, 2024).

However, in terms of large or dynamically changing networks, it can take a long time to solve an LP or ILP problem. To address this, the use of the combination of LP with other methods like heuristics, decomposition or machine learning to identify fast and more reactive decisions has been embraced by scientists. These combination techniques retain the precision and organization of LP as well as addressing the speed requirements of the current wireless and 5G networks (Luo, 2023; Lőrincz *et al.*, 2024).

#### **2.2.10 Linear Programming in Military and Defence Applications**

The uses of linear programming (LP) and its derivatives, such as mixed-integer linear programming (MILP), are also finding application in the military and defence contexts to make decisions when resources are limited. These approaches assist in specifying the objectives (cost reduction or a high coverage) and the constraints (available human resources or equipment capacity or response time). Baboş (2025) applied LP that has interval coefficients in order to model the uncertainty of the military operation, which makes the model more realistic in that some of the data are not precise. LP enables defence planners to discover the best resource-allocations even under uncertain situations (Baboş, 2025).

LP has been used in the distribution of defence resources in activities such as air defence or training. The model of Luo *et al.*, (2024) was designed to integrate MILP with decision-making techniques to distribute air defence equipment (radars, launchers, missiles) in a manner that minimizes the success of enemy attacks and allow consideration of the chance of a target surviving. In military training, Odion *et al.*, (2023) created a mixed integer programming model that provides an optimal resource allocation of training in the Nigerian Defence Academy which minimized cost and maximized performance in mission critical activities.

Since the exact optimization in LP/MILP might be computationally intensive, particularly in cases where the number of variables or uncertain data are many, recent studies have found that a combination of LP and heuristics or interval is a common practice in the military. This assists in accelerating the decision making process and address risk. A number of LP models have been developed to handle uncertainty in input data, such as interval coefficient models (Baboş, 2025). In addition, heuristic and evolutionary approaches have been integrated with MILP to identify near-optimal solutions when achieving full optimality is computationally impractical (Luo *et al.*, 2024; Odion *et al.*, 2023).

#### **2.2.11 Linear Programming in Marketing and Media Planning**

Linear programming (LP) is an apparent mathematical instrument assisting marketers in determining how to allocate a very strict budget among channels and campaigns. In the LP models, the marketer has a goal (such as reach maximization, conversions maximization or profit maximization) and puts constraints like cumulative budget, a minimum amount of money that must be spent on one channel or must cover target groups. LP and the integer or robust versions of the model enable planners to convert these targets and constraints into equations, which can be solved by a solver, delivering an optimum allocation based on the data (Odinaev & Afzalshohi, 2024).

Concrete media planning such as the selection of warrants to use, placement of the advertisements, and ranking of sponsored listing is also done using LP. Large online systems have developed ranking and allocation as LP or relaxed mixed-integer problems and discovered that the LP-based algorithms could enhance revenue and relevance in field experiments (Lu & Zhang, 2024). In short-term campaign approaches, marketers use LP in combination with sturdy optimization calculations to protect against the unpredictable costs of conversion or unstable advertisement costs, and robust LP generates plans that remain effective when the numbers in the input vary (Sedlářová Nehézová *et al.*, 2025).

Although strong, LP has some boundaries. Real marketing issues can be large, nonlinear, and have an overlap of the audience or time dynamics. Due to this reason, practitioners apply LP in combination with other tools such as media-mix modeling and heuristics, as well as simulations, to reduce diminishing returns, and inter-channel duplication or swiftly evolving performance metrics (Feger, 2024). The implication is that LP offers a solid and explainable foundation of budget and media decision making, and in combination with robustness or hybrid approaches, it offers marketers the ability to make safer and more measurable plans in unpredictable markets (Sedlářová Nehézová *et al.*, 2025; Lu & Zhang, 2024).

#### **2.2.12 Linear Programming in Environmental Management**

Linear programming (LP) has been significant in the management of the environment to enable decision-makers to strike a balance between environmental objectives, economic and technical bottlenecks. LP is used in waste management to develop systems that will reduce the costs of disposing waste materials as well as reduce adverse effects to the environment. In their work, Zhang *et al.*, (2024) gave an example of how to maximize the transportation and treatment of solid waste in the urban environment by considering the capacity limitation and the environmental needs through the use of an LP approach. Their study showed that LP can seek cost-effective ways of municipal waste management and support pollution and carbon emissions (Zhang *et al.*, 2024). Similarly, Liu and Cao (2023) applied mixed-integer LP to design waste-to-energy facility, maximize the effectiveness of recycling, and reduce the use of landfills.

LP is considered in pollution management in deciding on the emission levels and the manner in which industries will achieve the target levels at the minimal costs. Adewumi and Okafor (2023) used LP together with allocation of the limited resources in curbing pollution in different industries in Nigeria. Their model enabled them to reduce the overall emissions at a relatively cheap cost. In the same way, the analysis of the most efficient combination of the treatment technologies to reduce air pollutants in power plants was proposed by Al-Douri *et al.*, (2025) in the framework of the LP-based optimization model. Such studies indicate that the research on the environmental aspects and its impact on the economy allows balancing between natural defense and profitability of the economic process (Adewumi & Okafor, 2023; Al-Douri *et al.*, 2025).

The use of LP has also been highly implemented in the process of water resources allocation particularly in agriculture and local area planning. The work of Li *et al.*, (2024) employed a two-stage stochastic LP model to plan locations and water distribution of irrigation wells in Ethiopia, which made sure that the population had water at all times in case of inevitable weather change. Their work was able to show that LP could manage to balance the water requirements in farming, industry, and domestic consumption in a balanced and efficient manner. In general, LP provides a more scientific and adaptable method of utilizing scarce environmental resources, an opportunity to make governments and organizations develop sustainable frameworks of waste (recycling), pollution, and water management (Li *et al.*, 2024).

### 2.2.13 Linear Programming in Sports and Games Strategy

Linear programming (LP) assists coaches and analysts in making decisions in sports in a clear and data-driven manner by modeling strategic goals as math problems. For example, with salary limits, fatigue, or positions restrictions, LP is utilized to select an optimal starting lineup. Leaders can use LP to establish the optimal combination of players within realistic constraints by specifying an objective (such as maximize expected points or probability of victory) and constraints (minutes, budget, roster rules), among others (Smith, 2023).

Game planning and in-match strategy can also be done with the aid of LP. Analysts apply LP to assign playing time, substitute time, in order to optimize risk-reward play mixes. In soccer or basketball, an LP model can put plays or formations in any situation to maximize a scoring probability, and have a defensive risk exceed a limit. LP is used in e-sports and turn-based games to distribute scarce in-game resources (gold, actions or units) to the activities that the game offers the highest strategic payoff based on time or resource constraints (Garcia & Lee, 2024).

In games lineup and in-match selections, LP helps in the scheduling, tournament design, and allocation of training resources. Organizers of tournaments have used LP to create balanced schedules that avoid imbalances in travel and rest. Training staff have used LP to allocate scarce practice time to the most performance-enhancing skills. Since real sports issues often involve discrete decisions (play or not, start or bench), the combination of LP and integer programming, as well as heuristics, is often used to provide practical and near-optimal solutions as fast as possible (Patel *et al.*, 2022; Moreno, 2025).

## 3. DISCUSSION OF FINDINGS AND CHALLENGES

The review demonstrates that the Linear Programming (LP) remains a highly applicable tool to use in the resolution of real-life issues in various areas. Previously, the application of LP was in production scheduling, transportation and finance. Currently, its application extends to the new fields of energy management, environmental protection, healthcare planning, telecommunications, and smart cities. The applications they provide can be used by organizations and governments to make more effective decisions regarding the efficient use of limited resources and minimizing waste (Gupta & Sharma, 2023; Al-Harbi & Rahman, 2025). Integration of LP and artificial intelligence (AI) as well as machine learning has also enabled it to be stronger and more adaptable to handle uncertain or dynamic information (Chen & Li, 2024). In smart cities, LP is used to control the traffic system, power consumption, and garbage collection in order to make cities more clean and effective (Pukkala *et al.*, 2025).

Nevertheless, there are still certain difficulties. The LP models tend to model simple and fixed relationship between variables, whereas the reality on the ground is most of the times complicated and obscured (Patel & Kaur, 2023). This implies that not all factors that influence a decision can always be reflected in LP. The next issue is that as data becomes larger and more complicated, solving the LP models becomes more computer-intensive and faster. In addition, it is not always easy to gather precise and trustworthy information that may influence the outcomes. Nevertheless, recent works reveal that with the implementation of LP with AI, cloud computing, and other sophisticated optimization methods, these problems can be mitigated. It further turns LP into an even more useful tool in the contemporary decision-making and sustainable planning (Chen & Li, 2024; Gupta & Sharma, 2023).

## 4. CONCLUSION AND FUTURE PROSPECTS

As it can be seen in the review, Linear Programming remains highly applicable and useful in the modern dynamic world. This is why it is a powerful tool in most areas, and in particular, in the fields of sustainability and digital

transformation, because it is able to find the optimal solution to complex problems. LP enables organizations to make decisions, save, and plan better to balance economic growth and environmental protection (Al-Harbi & Rahman, 2025). Increasingly connected with AI, smart systems, and big data, LP is contributing to the solution of the global problems like energy deficiency, waste disposal, and climate change (Pukkala *et al.*, 2025).

The conclusion sufficiently aligns with the Decision Theory which serves as the guiding framework of the study. Decision Theory examines how individuals or organizations make cautious decisions among the various alternatives to produce the best outcomes, particularly in circumstances where there are restrictions or uncertainty. The study by Alexander *et al.*, (2022) can also be interpreted in this manner since the authors used the Decision Theory to learn how various stakeholders make pragmatic and moral decisions in the context of the complex sustainability problem like deforestation and the need to pursue the Sustainable Development Goals (SDGs).

In the future, LP is not going to lose its significance, it will continue to become more flexible. The emergence of new technologies (quantum computing, optimization of clouds, etc.) will help LP to be faster, more precise, and able to process complex data (Gupta & Sharma, 2023). In order to remain relevant, researchers and professionals should continuously enhance its algorithms and connect it with other modern technologies. When this occurs, LP will remain relevant in making superior choices and encouraging smarter and more sustainable systems in the industries and governments worldwide.

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