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Linear Programming as a Mathematical Model in Solving Realistic Optimization Problems: A Theoretical Study

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ABSTRACT
Linear Programming is a branch of applied mathematics widely used to solve optimization problems in various fields, such as industry, economics, transportation, agriculture, and resource management. This method plays an important role in assisting decision-making by determining the optimum solution by considering various limitations expressed in the form of linear constraints. The ability of Linear Programming to transform real-world problems into mathematical models makes it an effective approach in analyzing and solving complex problems. This article aims to theoretically examine the role of Linear Programming as a mathematical modeling tool in representing and solving various optimization problems in realistic contexts. The study uses a library research method by reviewing and analyzing various relevant scientific literature sources, including reference books, journal articles, and previous research results related to Linear Programming, optimization, and mathematical modeling. The results of the study show that Linear Programming is able to represent various real-world problems through its main components, namely decision variables, objective functions, and constraints. In addition, the geometric interpretation of Linear Programming through the feasible region and corner points provides a deeper understanding of the process of determining the optimum solution. Various studies also show that linear programming has been widely applied in production optimization, goods distribution, agricultural planning, and limited resource allocation. Therefore, linear programming can be seen as an effective method for mathematical modeling and solving optimization problems in various realistic contexts.

KEYWORDS
Linear Programming, Optimization, Mathematical Modeling, Realistic Problems, Applied Mathematics.

1. INTRODUCTION

Mathematics is a branch of science that plays a crucial role in understanding, analyzing, and solving various problems that arise in real life. Besides being a calculation tool, mathematics also functions as a modeling tool that allows a phenomenon or problem to be represented in a more systematic and measurable form. Through mathematical modeling, various complex problems can be simplified into models that can be analyzed to obtain effective and rational solutions. The ability of mathematics to represent real-world problems makes it a crucial instrument in the decision-making process in various fields, such as economics, industry, transportation, agriculture, and resource management [1, 2].

In these various fields, the problems frequently encountered involve achieving the best results from limited resources. These types of problems are known as optimization problems. Optimization is the process of determining the best solution from a number of available alternatives, taking into account various constraints affecting the system. The need for optimization methods is increasing along with the increasing complexity of problems in the industrial, business, logistics, and development planning sectors. Therefore, a mathematical approach is needed that can provide optimal solutions systematically and scientifically [3, 4].

One of the most widely used optimization methods in applied mathematics is Linear Programming. Linear Programming is a mathematical optimization technique used to determine the maximum or minimum value of an objective function by considering a number of constraints expressed in the form of linear equations or inequalities ([2]). This method was first developed by George B. Dantzig in the mid-20th century and until now remains one of the important analytical tools in the field of operations research and decision making [5]. The advantage of Linear Programming lies in its ability to transform real problems into structured mathematical models that allow for obtaining optimal solutions efficiently.

In its application, Linear Programming has been used to solve various real-world problems, such as production planning, goods distribution, activity scheduling, inventory management, resource allocation, and agricultural land use planning. In the industrial sector, Linear Programming is used to determine product combinations that provide maximum profits by considering the limitations of raw materials, labor, and production capacity. In the field of transportation and logistics, Linear Programming is used to minimize the cost of distributing goods from several sources to various destinations. Meanwhile, in the agricultural sector, Linear Programming is used to determine planting patterns or land allocation that can produce optimum profits by considering the availability of land, water, and capital [6, 7, 8].

The successful application of Linear Programming in various fields is inseparable from its capabilities as a mathematical modeling tool. The modeling process allows a real-world problem to be represented in the form of decision variables, objective functions, and constraints that describe the actual system conditions. Thus, Linear Programming serves not only as a technique for solving optimization problems but also as a means of understanding the relationships between variables in a system and evaluating various possible decision alternatives [9, 10].

Although Linear Programming has been widely applied in various fields, studies examining its role as a mathematical model in representing realistic optimization problems still need to be strengthened. Most literature emphasizes the procedural aspects of model solution or application to specific cases, while discussions of the relationship between mathematical modeling processes, geometric representations, and comprehensive optimization problem solving are still relatively limited. Therefore, a study is needed that can integrate these various perspectives to provide a more comprehensive picture of the role of Linear Programming in solving realistic problems.

Based on this description, this article aims to theoretically examine Linear Programming as a mathematical model in solving realistic optimization problems. The study focuses on the basic concepts of Linear Programming, the mathematical modeling process, the geometric interpretation of solutions, and various forms of its application to real-world problems. The results of this study are expected to contribute to strengthening the understanding of the role of Linear Programming as an important method in applied mathematics and optimization-based decision-making.

2. LITERATURE REVIEW

Linear Programming is an optimization method in operations research used to determine the best solution to a problem involving limited resources. This method aims to maximize or minimize an objective function by considering a number of constraints expressed in the form of linear equations or inequalities [3]. According to Taha, the Linear Program model consists of three main components, namely decision variables, objective function, and constraints. Decision variables represent choices whose values can be determined, the objective function indicates the goals to be achieved, while constraints describe the limits that must be met in the system being analyzed [4].

In general, the mathematical form of a Linear Program can be expressed as:

Maximize/minimize: $Z = \sum_{j=1}^{n} c_j x_j$

with obstacles

$$\sum_{j=1}^{n} c_j x_j \leq b_i, \;\; i = 1,2,\ldots,m$$

$$x_j \geq 0, \;\; j = 1,2,\ldots, n$$

This model allows various real-world problems to be represented mathematically so that optimal solutions can be systematically sought [11].

Mathematical modeling is the process of representing real-world phenomena or problems in mathematical form to gain a more structured understanding and solutions [2]. In the context of optimization, Linear Programming is one of the most widely used approaches because it can illustrate the relationship between the desired goal and the various constraints faced. According to Edwards and Hamson [1], the mathematical modeling process generally includes problem identification, determining relevant variables, establishing mathematical relationships between variables, analyzing the model, and interpreting the results in a real-world context. Linear Programming allows this process to be carried out systematically, so that the resulting decisions have a clear quantitative basis.

Luenberger and Ye [9] stated that the success of a Linear Programming model depends heavily on the accuracy of identifying decision variables, constructing objective functions, and formulating constraints that are appropriate to real-world conditions. Therefore, Linear Programming serves not only as a calculation tool but also as a means of understanding the structure of the problem being analyzed. One important characteristic of Linear Programming is its ability to be represented geometrically, especially in cases involving two decision variables. Each constraint in a Linear Programming model can be depicted as a solution region on the coordinate plane, while the intersection of all regions that satisfy the constraints is called the feasible region [4]. According to Winston, the optimal solution to a Linear Programming problem always lies at one of the corner points of the feasible region. This principle, known as the corner point theorem, is the basis for solving Linear Programming using graphical methods [8].

Geometric representations provide a better understanding of the relationship between objective functions and constraints and help interpret the obtained solutions in the context of real-world problems [10]. Various studies have shown that linear programming has been widely applied in solving optimization problems in various sectors. Alotaibi and Nadeem reported that linear programming is widely used in agriculture to determine optimal cropping patterns and resource allocation. The results of this study indicate that the use of linear programming can improve the efficiency of land, labor, and capital utilization [6].

Kunwar and Sapkota demonstrated that linear programming can be applied to various real-world problems, such as production optimization, transportation, and resource management. This research confirmed that linear programming models can provide effective solutions to problems involving multiple constraints [7]. Furthermore, Hillier and Lieberman, as well as Taha, explain that linear programming is one of the most widely used optimization methods in operations research due to its simplicity and ability to produce optimal solutions that can be implemented in various real-world situations [3, 4].

Based on these various studies, it can be concluded that Linear Programming plays a crucial role as a mathematical modeling tool in solving realistic optimization problems. However, further studies are needed that comprehensively integrate the fundamental concepts, mathematical modeling, geometric interpretation, and their application to various real-world contexts. Therefore, this article attempts to present a theoretical study that connects these various aspects into a coherent discussion.

3. METHODOLOGY

This research uses a library research method with a theoretical approach to examine the role of Linear Programming as a mathematical model in solving realistic optimization problems. A library research method utilizes various literature sources as the primary data source to gain a comprehensive understanding of a concept, theory, or phenomenon under study [12].

Research data was obtained from various scientific literature sources related to Linear Programming, optimization, operations research, and mathematical modeling. Data sources include books, journal articles, proceedings, and other scientific publications relevant to the research focus. The literature used was selected based on its relevance to the theme, the credibility of the sources, and its contribution to the discussion.

Data collection was conducted through documentation studies by tracing, identifying, and reviewing various relevant literature. Furthermore, the data were analyzed using content analysis techniques, which are analytical techniques used to systematically identify, organize, and interpret information contained in documents or written sources [13]. The analysis was conducted through a process of grouping themes, interpreting concepts, and synthesizing theories related to Linear Programming as a mathematical model. The results of the analysis were then presented descriptively to obtain a comprehensive picture of the basic concepts of Linear Programming, its role in mathematical modeling, geometric interpretation of solutions, and its application in various realistic optimization problems.

4. RESULT & DISCUSSION

4.1 Characteristics of Linear Programs in Optimization Problems

Linear programming is a widely used optimization method in various fields due to its ability to address problems involving limited resources and the need to obtain optimal results. The advantage of linear programming lies not only in its ability to produce optimal solutions, but also in its simple and systematic mathematical structure, making it easy to apply to various real-world problem contexts. Therefore, linear programming is an important tool in operations research, planning, and decision-making [3].

The success of applying Linear Programs in solving optimization problems is based on several fundamental characteristics that differentiate them from other optimization models. One of the main characteristics is linearity, namely the relationship between decision variables and objective functions and constraints expressed in linear form. This assumption allows changes to a variable to result in a proportional change to the value of the objective function or resource use. Linearity provides convenience in the model formulation process while allowing optimum solutions to be obtained through efficient mathematical procedures [4].

The next characteristic is additivity, namely the contribution of each decision variable to the objective function and constraints is independent so that the total contribution is obtained by adding up all the components involved. In the context of production, for example, total profit is the result of adding up the profits obtained from each type of product. The principle of additivity allows relationships between variables to be represented simply without having to consider complex non-linear interactions [11].

Linear programming also has the characteristic of divisibility, meaning that decision variables are assumed to take on fractional values or non-negative real numbers. This assumption allows for more flexibility in obtaining optimal solutions than if variables were limited to integer values. Although in practice, fractional solutions may need to be adjusted, the divisibility assumption provides an important mathematical foundation for the optimization process [9].

Furthermore, linear programming assumes certainty regarding all model parameters. The coefficients of the objective function and constraints are assumed to be known and unchanged during the analysis process. This assumption allows models to be built based on clear information, allowing objective evaluation of the resulting solutions. In reality, some problems may contain uncertainty, but linear programming remains an important starting point before developing more complex models such as stochastic programming or robust optimization[8].

Another equally important characteristic is non-negativity, meaning that decision variables are not permitted to have negative values. This assumption is consistent with most real-world problems, as product quantity, resource allocation, land area, and distribution volume generally cannot have negative values. With the non-negativity requirement, the resulting solution region remains meaningful within the context of the problem being analyzed [10].

This combination of characteristics makes Linear Programming an effective method for representing various optimization problems. The relatively simple model structure allows real-world problems to be translated into mathematical form without losing important information related to the system's objectives and limitations. On the other hand, the existence of these assumptions also indicates that not all problems can be directly modeled using Linear Programming. Therefore, the successful application of Linear Programming depends heavily on the compatibility between the characteristics of the problem at hand and the basic assumptions underlying the model.

In the context of applied mathematics, the characteristics of Linear Programming provide a strong foundation for modeling various real-world phenomena. The ability to link optimization objectives to resource constraints through structured mathematical relationships makes Linear Programming one of the most relevant and widely used approaches today. This characteristic allows Linear Programming to be applied in various sectors, from manufacturing and transportation to agriculture and even resource management.

4.2 Linear Programming as a Mathematical Representation of Realistic Problems

One of the important roles of applied mathematics is to provide models capable of representing real-world phenomena and problems in mathematical form. Mathematical representation allows a complex problem to be simplified into a more organized structure that can be analyzed systematically. In the context of optimization, Linear Programming is a widely used approach because it can illustrate the relationship between the desired goal and the various limitations faced within a system [2].

As a mathematical model, Linear Programming translates the elements contained in a real-world problem into clearly defined mathematical components. The process begins with identifying the desired goal, such as maximizing profit, increasing efficiency, or minimizing costs. Next, decision variables are determined, representing the alternative courses of action. Various limitations affecting the achievement of the goal are then formulated as constraints that must be met. The relationship between the goal, decision variables, and constraints forms a model that can be analyzed to obtain the best solution [1].

Linear programming's ability to represent realistic problems is supported by its relatively simple model structure, yet it is capable of depicting various important relationships within a system. Through the abstraction process, factors deemed relevant are retained in the model, while elements that have no significant influence are ignored. This approach allows complex problems to be reduced to mathematical models that are easier to analyze without losing key characteristics that influence decision-making [9].

In practice, mathematical representation through linear programming has been applied in various fields, such as production planning, goods distribution, resource management, and agricultural land use planning. Although the problem contexts differ, all these applications share common characteristics: an objective to be optimized and resource constraints to be considered. These shared characteristics demonstrate linear programming's high flexibility in representing various types of optimization problems [3].

The accuracy of a mathematical representation depends heavily on the accuracy of the formulation of decision variables, objective functions, and constraints. A model that fails to adequately represent real-world conditions may produce a mathematically optimal solution that lacks practical application. Therefore, the modeling process is a crucial step in using Linear Programming. The quality of the resulting solution is determined not only by the solution method but also by the model's ability to accurately represent the real-world problem.

Based on this description, Linear Programming can be viewed as a bridge between real-world phenomena and mathematical analysis. Its ability to transform complex problems into structured models makes Linear Programming a crucial tool in applied mathematics, particularly in supporting rational, measurable, and optimization-based decision-making.

4.3 Geometric Interpretation and Optimal Solution

One characteristic that distinguishes Linear Programming from many other optimization models is its ability to be interpreted geometrically. In cases involving two decision variables, the relationship between the objective function and constraints can be visualized in a coordinate plane, providing a more intuitive understanding of the process of finding the optimal solution. This geometric approach not only helps understand the model's structure but also explains the mathematical reasoning behind obtaining an optimal solution [4].

In the geometric representation of Linear Programming, each constraint is represented by a boundary line that divides the coordinate plane into two regions. The set of all points satisfying a constraint forms a feasible solution region. When multiple constraints are applied simultaneously, the intersection of these solution regions produces a region known as the feasible region. This region contains all alternative solutions that satisfy the model's requirements, thus forming the search space for the optimal solution [3].

Geometrically, the objective function can be viewed as a set of parallel lines whose values change according to the direction of the shift. The optimization process is carried out by shifting the objective function line until it reaches a maximum or minimum value that remains within the feasible region. The final point of intersection between the objective function line and the feasible region indicates the optimal solution achievable by the model.

One important result in Linear Programming theory is that an optimal solution, if it exists, will be at one of the corner points of the feasible region. This principle is known as the corner point theorem. This theorem provides a strong mathematical foundation for various Linear Programming solution methods, including graphical and simplex methods. Thus, the search for the optimal solution need not be conducted at all points within the feasible region, but rather focused on the corner points formed by the intersection of the model's constraints [11].

Geometric interpretation also provides an understanding of the influence of constraints on the resulting solution. Adding or changing a constraint will alter the shape of the feasible region, potentially changing the location of the optimum solution. Therefore, the feasible region serves not only as a representation of the set of eligible solutions but also as a tool for understanding the model's sensitivity to parameter changes. In the context of decision-making, this information is crucial because it allows for the analysis of various possible scenarios.

The advantage of the geometric approach lies in its ability to explain the relationship between the mathematical and practical aspects of a problem. The feasible region describes the constraints encountered in the real world, while the optimum point represents the best decision that can be made within those constraints. Thus, the geometric interpretation demonstrates that the optimum solution is not simply the result of mathematical calculations, but rather the logical consequence of the interaction between the desired goal and available resources.

Through geometric interpretation, Linear Programming demonstrates how mathematical concepts can be used to support rational and systematic decision-making. This approach also strengthens the role of Linear Programming as an analytical tool in applied mathematics, capable of connecting mathematical representations with the real-world conditions under study.

4.4 Analysis of the Modeling Process in Realistic Cases

One of the main strengths of Linear Programming lies in its ability to transform complex real-world problems into structured mathematical models. Through the modeling process, various components of a system, such as the desired objectives, available resources, and operational constraints, can be represented mathematically, enabling objective and systematic analysis. Therefore, modeling is a crucial step in implementing Linear Programming because the quality of the resulting solution depends heavily on the model's ability to adequately describe real-world conditions [4].

To illustrate this process, consider the case of agricultural land allocation. A farmer owns 10 hectares of land to be used to grow two commodities: corn and soybeans. Each hectare of corn yields a profit of Rp5 million, while each hectare of soybean yields a profit of Rp4 million. In addition to limited land area, the farmer also faces a limited labor force available to support the cultivation of these two commodities.

The initial stage of modeling involves defining decision variables that represent the decisions to be made. In this case, the decision variables are defined as:

$x_1 =$ area of corn fields (hectares)

$x_2 =$ area of soybean fields (hectares)

Since the farmer's primary goal is to maximize profits, the objective function can be formulated as:
Maximize

$$Z = 5x_1 + 4x_2$$

where Z represents the total profit obtained from land use.

Resource limitations are then expressed in the form of constraints. The area of land used must not exceed the area of land available, resulting in the following constraints:

$$x_1 + x_2 \leq 10$$

Meanwhile, labor limitations result in constraints:

$$4x_1 + 2x_2 \leq 24$$

In addition, the land area allocated for each commodity cannot possibly have a negative value so it applies:

$x_1 \geq 0$

$x_2 \geq 0$

The resulting model demonstrates how the elements of a real-world problem are translated into mathematical language. Decision variables represent the choices available to farmers, the objective function describes the desired goals, and constraints reflect the resource limitations that must be met. The relationship between these three components forms an optimization system that can be further analyzed to obtain the best decision. Geometrically, this system of constraints produces a feasible region containing all land use combinations that meet the model's requirements. This feasible region can be visualized as shown in **Figure 1**. Analysis of the corner points of the feasible region is performed to determine the optimum value of the objective function. The results of the objective function evaluation at each corner point are shown in **Table 1**.

Based on the evaluation results, the maximum value of the objective function is obtained at point (2,8) with a Z value=42. In the context of the problem, this result indicates that the maximum profit is obtained when the farmer allocates 2 hectares of

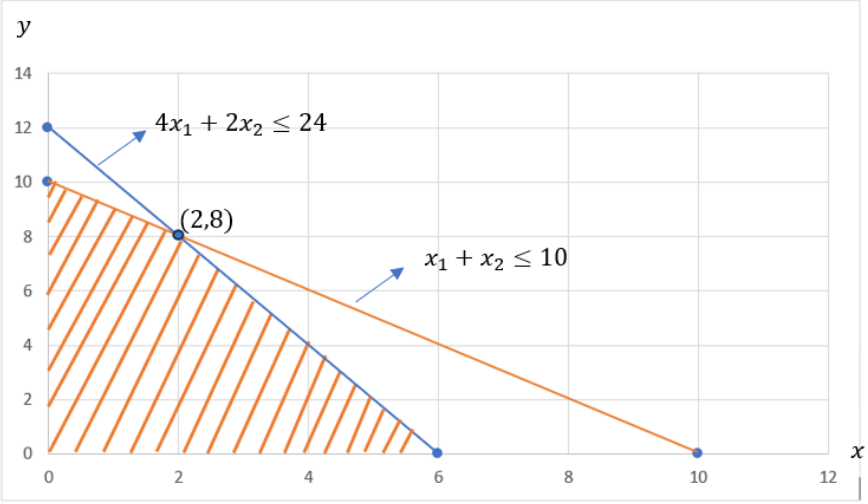


Figure 1. Feasible Area and Optimal Solution in the Agricultural Land Allocation Model

Table 1. Objective Function Values at Corner Points of the Feasible Region

Corner Point	$Z = 5x_1 + 4x_2$
$(0,0)$	0
$(0,10)$	40
$(6,0)$	30
$(2,8)$	42

land to corn and 8 hectares to soybeans. This solution represents the most efficient combination of resource use based on the available constraints.

This case demonstrates that Linear Programming functions not only as a mathematical calculation technique but also as a tool for understanding the relationship between objectives and constraints in a system. Through the modeling process, various decision alternatives can be rationally compared to obtain the most profitable solution. Thus, Linear Programming plays a crucial role in supporting decision-making in various fields involving the optimization of resource use.

4.5 Implications and Potential of Implementing Linear Programs in Various Sectors

Linear programming is an optimization method with a broad scope of application in various fields. Its ability to optimally allocate limited resources makes this method relevant for use in various problems involving decision-making. Through mathematical modeling, linear programming allows the relationship between a system's objectives and constraints to be systematically analyzed, resulting in efficient and rational solutions [14, 3].

In the industrial and manufacturing sectors, linear programming is widely used to determine production combinations that provide maximum profit or minimum costs. Companies often face limitations in raw materials, labor, machine capacity, and production time. By utilizing linear programming, these limitations can be incorporated into the model to obtain the most profitable production decisions based on available resources [4]. Recent developments indicate that linear programming remains the primary approach in production optimization and capacity planning due to its ability to produce efficient solutions in systems involving many decision variables [14].

In the transportation and logistics sector, linear programming plays a role in determining efficient distribution patterns. Problems such as determining delivery routes, vehicle allocation, and the distribution of goods from multiple sources to multiple destinations can be modeled using a linear optimization approach. The application of this method helps reduce distribution costs while increasing operational efficiency in logistics systems [8]. In addition to its use in goods distribution, the linear optimization approach is also widely applied in reverse logistics systems and sustainable supply chain management to improve operational efficiency while reducing distribution costs [15].

In the agricultural sector, linear programming has been widely used to optimize the use of land, labor, irrigation water, and various other resources. Through mathematical modeling, farmers and farm managers can determine commodity combinations that generate maximum profits without exceeding available resource constraints. Various studies have shown that the use of linear programming can improve the efficiency of farm management and support more effective agricultural planning [6]. Recent research developments indicate that linear programming techniques are used not only for land use optimization but also for food production planning, animal feed formulation, and consumption pattern optimization, taking into account various available resource constraints [16].

Furthermore, Linear Programming also plays a crucial role in resource management and organizational planning. Various decisions related to work scheduling, budget allocation, service capacity determination, and investment planning can be analyzed using Linear Programming models. This method's ability to identify the best solution from a number of alternatives makes it a crucial tool in supporting data-driven decision-making processes. Advances in computing technology have further expanded the application of Linear Programming in various fields. Currently, solving optimization models can be done with the help of specialized software, enabling the analysis of more complex problems involving a large number of variables and constraints. This situation demonstrates that Linear Programming remains highly relevant in addressing the challenges of resource management in the modern era. In addition to conventional sectors, Linear Programming is also increasingly used in modern digital systems, such as communications network optimization, data center management, and resource allocation in large-scale computing systems. These developments demonstrate that Linear Programming remains a relevant optimization method for addressing the challenges of decision-making in the digital age [17].

Based on these various applications, Linear Programming can be viewed as a crucial tool in applied mathematics, bridging mathematical theory with practical needs across various sectors. Its ability to generate optimal decisions makes this method not only academically valuable but also significantly contributes to solving various problems faced by society and industry.

5. CONCLUSION

Linear programming is an optimization method in applied mathematics that has the ability to represent various realistic problems in structured mathematical models. Through its main components of decision variables, objective functions, and constraints, Linear programming enables systematic decision-making while considering the limitations of available resources. The linearity characteristic of the model makes Linear Programming effective in analyzing the relationship between optimization objectives and various limiting factors in a system.

This study demonstrates that the modeling process plays a crucial role in the application of Linear Programming. A real-world problem can be transformed into a mathematical model by identifying decision variables, formulating objective functions, and establishing constraints appropriate to the problem's conditions. This mathematical representation allows for objective analysis, resulting in optimal solutions that can be interpreted within the context of the problem under study.

Through geometric interpretation, Linear Programming also demonstrates a clear relationship between the feasible region, the objective function, and the optimum solution. This concept provides an understanding that the best solution is obtained from the interaction between the desired objective and the resource constraints that must be met. Analysis of the agricultural land allocation case demonstrates that Linear Programming is capable of producing optimal decisions through a systematic and measurable modeling process.

Furthermore, this study confirms that Linear Programming has broad application potential in various sectors, such as manufacturing, transportation and logistics, agriculture, and resource management. Its ability to optimize resource use makes Linear Programming a crucial instrument in supporting rational, efficient, and mathematically based decision-making. Therefore, Linear Programming remains relevant for use in various optimization problems that evolve along with the increasing complexity of needs in various areas of life.

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