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Contrast between traditional productivity measurement models and a transdisciplinary one

Contraste entre modelos de medición de productividad tradicionales y uno transdisciplinar

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ABSTRACT: In this article, a comparison between nine traditional models of productivity measurement and a transdisciplinary model is made. The study includes a description of the characteristics, advantages, and disadvantages of the most used models worldwide by for-profit organizations, as well as those of a new transdisciplinary model. The scientometric and bibliometric analyses are the primary sources in the definition of the representative elements of each model and the particularities that influence the measurement of company productivity. In addition, applied research is used through inquiry to professionals from different areas, businessmen, employees, and researchers related to the manufacturing area, with the aim of obtaining differential information about the models. The results indicate that the use of the total productivity measurement model predominates due to ease of implementation; on the other hand, data envelopment analysis (DEA) is little used because it is strongly impacted when comparing multiple variables; economic models are generally used to estimate government taxes. Finally, the research shows that the generalization of the use of a transdisciplinary model to measure productivity is feasible; however, the model requires an integral structure that allows it to adapt to changing global conditions.

RESUMEN: En este artículo se realiza la comparación entre nueve modelos tradicionales de medición de la productividad y un modelo transdisciplinar. El estudio incluye la descripción de características, bondades y desventajas de los modelos más usados a nivel mundial por las organizaciones con ánimo de lucro; así como las del nuevo modelo transdisciplinar. El análisis cienciométrico y bibliométrico es fuente primaria en la definición de los elementos representativos de cada modelo y de las particularidades que influyen en la medición de la productividad de las empresas; complementariamente, se emplea la investigación aplicada mediante indagación a profesionales de diferentes áreas, empresarios, empleados e investigadores relacionados con el área de manufactura, con el objetivo de obtener información diferencial acerca de los modelos. Los resultados indican que predomina el uso de los modelos de medición parcial y total de la productividad por facilidad de implementación; por otro lado, el análisis envolvente de datos (DEA) muestra alta variabilidad porcentual en los resultados cuando los datos no son homogéneos. Los modelos económicos generalmente sirven para estimar gravámenes gubernamentales y son de difícil entendimiento para algunos empresarios. Finalmente, la investigación muestra que la generalización del uso de un modelo transdisciplinar para medir la productividad es factible; no obstante, el modelo requiere una estructura integral que le permita adaptarse a las cambiantes condiciones globales.

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1. Introduction

Survival on Earth is determined by several factors: one of them is the capacity of goods and services to be produced to meet the needs of a demographically exploding universe, full of demanding challenges and permanent change; that capacity is the productivity with which the demands of the population are responded to.

Productivity is the effectiveness with which an organization can demonstrate its level of operation. It is understood as the relationship between the level of final production obtained and the resources necessary to achieve it. This works correctly when there is an input resource and one output. Still, in most cases, several inputs aact simultaneously at the beginning, during, and at the end of the processes. In the first case, a partial calculation of the indicator is generated, leaving aside other factors that significantly affect the measurement.

There are several terms to express productivity: partial, average, gross, net, total, valued, and marginal. These topics give rise to the indicator measurement methods [1, 2]. The difference between expression and measurement of productivity lies in the fact that the expression is the descriptive way in which the term is denoted, while the measurement involves the mathematical notation and the procedure of how its application is carried out. Likewise, productivity is analyzed from quantitative and/or qualitative approaches, predominating the use of quantitative techniques. However, some companies use qualitative methods to complement the measurement. Both models are considered traditional, but qualitative models lack mathematical modeling.

Traditional productivity measurement models use the value of organizational elements acting individually or collectively to calculate the parameter or determine the relative contribution to business wealth; they also include mathematical models to compare the efficiency of similar resources and select the best. Some economic models include exact variables unrelated to labor, such as technological renewal investment in calculating productivity, assuming a contemporary position. Regarding qualitative models, companies use the measurement of soft factors independent of the productivity indicator, through technical instruments directed by the human management area for decision making.

The transdisciplinary model integrates traditional models with elements of Complex Thinking originating in social and human factors in such a way that the set of variables is chosen, taking into account the impact on the performance of the productive units both internally and externally, evidencing the presence of qualitative factors.

In measuring productivity, it is necessary to correctly determine the exact variables that affect the performance and yield of the productive units on which the productivity analysis is carried out. However, the possible effects of the integration of variables emanating from complexity and the human sciences in the models need to be validated. In the real sector, the presence of qualitative factors significantly impacts the processes. It has also been evident that they are not considered. One option to solve this difficulty is to incorporate elements of complex thinking originating from transdisciplinary factors into traditional measurement models.

Unlike traditional ones, some models try to include at least one human factor, [3] establishing a productivity model of the human factor for the electrical energy generation process, in which a main hypothesis and twenty-six auxiliary hypotheses are proposed. In this research, a factor analysis using SPSS statistical software by applying structural equation modeling (SEM) techniques is performed and causal relationships between variables are established, managing to verify the null hypothesis and 17 alternative hypotheses through unconventional multifactorial analysis, solving the questions of research: What are the human variables that affect the productivity of the process? Is it possible to establish a productivity model that considers the impact of the human factor on the process? And can the multifactor method be used to measure process productivity? The previous example is a good guide to formulating a transdisciplinary productivity model in which the research questions must be solved: how can exact, social and human variables be integrated into a transdisciplinary productivity model? What is the effective method for mathematical formulationof the transdisciplinary model for measuring productivity? How can we ensure that the development of the model is viable and differentiating?

2. Characterization of the models

This section describes the characteristic elements of each productivity measurement model, its mathematical formulation or graphic representation if present, and some case examples applied at a global level. Regarding the transdisciplinary model, the mathematical formulation is omitted since it is currently undergoing computational validation.

2.1 Measurement of total, partial, and relative productivity TRP

The total measurement includes all the elements used by the system; that is to say, the output reflects the added value of the set of input elements of the entire system, and the partial involves a single resource. Relative productivity refers to the use of virtual scalars that must be included in the measurement of productivity, when there are several resource variables and several product variables.

As previously stated, productivity is the relationship between the volume of final production and the materials used to achieve it [4]. This is how Equation 1 represents the definition of productivity above [5].

$$\text{Productivity} = \frac{\text{created production}}{\text{resource consumed}} = \frac{\text{output}}{\text{Input}} \quad (1)$$

The concepts of output and input in Equation 1 refer to the result obtained, and the resource used, respectively. This formula works when there is only an input and an output; however, in most cases, there are several types of resources and several results to obtain. Therefore, it is necessary to carry out some previous steps to correctly filter the variables (inputs and outputs) that really affect the performance of the productive units, on which the corresponding productivity analysis is carried out [6].

The first step in the measurement is to exhaustively determine each of the factors that are relevant to achieving the objectives of the production unit. The next step consists of measuring each chosen resource, to determine what degree of use has been made in the creation of the result in the productive unit.

Once this first part of the analysis has finished, the determination of productivity begins, and although the results are various, the productivity of a decision-making unit (DMU) is a scalar, and therefore, an expression is necessary where all the inputs and all the outputs appear from the DMU that are related to productivity [7]. In this case, the analyst encounters the difficulty of having to group resources (inputs) and results (outputs) in the same expression, which may be different and, therefore, other measurement units, making Equation [1] proposed by Farrel inoperative. To solve this problem, the concepts of virtual input and output appear to be the aggregation of outputs and inputs scaled by means of weight so that the result is dimensionless and, therefore, independent of the scale used. In this way, Equation 2 analyzes the productivity considering several inputs and several outputs.

$$\text{Productivity} = \frac{\text{weighted sum of outputs}}{\text{weighted sum of inputs}}$$
$$\text{Productivity} = \frac{\sum_{r=1}^{s} u_{rj} * y_{rj}}{\sum_{i=1}^{m} v_{ij} * x_{ij}} \quad (2)$$

Where the numerator consists of the sum of the different output variables Y with their respective weights U, and the denominator involves the sum of the different input variables X with their respective pondered weights V.

Based on the application of Equation (2), a scalar value of the productivity of each DMU analyzed will be obtained without worrying about the measurement units used by each variable considered in the model. In addition to the above, it is emphasized that identifying inputs and outputs in the evaluation of DMUs is a task as difficult as it is crucial. The inputs should capture all the resources that impact the outputs, and the outputs should reflect all the useful results based on what we want to evaluate the DMUs in.

That is why the measure of productivity, obtained separately from Equation 2, does not provide any reference to how the available resources are being used to produce the results regarding other DMUs. That is, when a DMU is compared with other similar units, the productivity study can be more helpful. This is where the concept of relative efficiency appears.

Equation 3 represents the concept of relative efficiency, where each DMU is compared to the best in terms of productivity. This means that the DMU that obtains the value of the unit with said formula indicates that it is efficient, and the rest of the DMUs that obtain a value below the unit will be classified as inefficient.

$$\text{Effectiveness}_j = \frac{\text{Productivity}_j}{\text{Productivity}_0} = \frac{\text{Virtual outputs}_j / \text{Virtual inputs}_j}{\text{Virtual outputs}_0 / \text{Virtual inputs}_0}$$
$$\text{Effectiveness}_j = \frac{\sum_{r=1}^{s} u_{rj} * y_{rj} / \sum_{i=1}^{m} v_{ij} * x_{ij}}{\sum_{r=1}^{s} u_{rj} * y_{rj} / \sum_{i=1}^{m} v_{ij} * x_{ij}} \quad (3)$$

Efficiency measures are based on estimates of the degree to which a given DMU could have achieved a higher level of outputs for a certain level of its inputs or the degree to which it could have used fewer inputs for a given level of output. Based on the foregoing, consideration should be given to which of the two groups of variables (inputs or outputs) has greater control when making improvement decisions, and thus, analyze the technical efficiencies of the inputs or the outputs. Thus, the following definitions are obtained:

Technical efficiency of the inputs: it is the maximum proportion in which all the inputs of the DMU can contract radially without causing deterioration (decrease) in the level of its outputs. *Technical efficiency of the outputs:* it is the maximum proportion in which all the outputs of the DMU can expand radially without causing deterioration in the level of its inputs (increase).

2.2 Data envelopment analysis DEA

Founded on the previous model and to optimize the weights, DEA contains a series of mathematical models based on linear programming, which involve the productivity and efficiency formulas presented in the previous section, in such a way that each DMU obtains its best efficiency and can be able to make a fair comparison between all the DMUs involved.

The definition of the DMU as an evaluation unit refers to the unit whose efficiency is to be measured relative to other units of its class. It is one of the first steps for the comparative performance evaluation [8]. DMUs must be homogeneous units because they use the same type of resources to obtain the same type of results, albeit in variable amounts.

In general terms, the central idea of DEA is to evaluate the efficiency with which a DMU is handling the transformation process compared to other DMUs involved in the same process. However, it is necessary to previously define the group of variables (inputs or outputs) that can be controlled and the type of frontier that will be handled. Figure 1 summarizes these parameters.

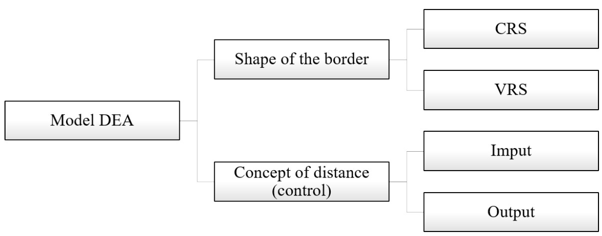

Figure 1 Initial parameters to choose the DEA model [9]

When the frontier is the Constant Return Scale (CRS), it indicates that the DMUs evaluated will be able to reach the productivity of the efficient ones regardless of their size. On the other hand, the Variable Return Scale VRS frontier indicates that each DMU is compared with those of the same size, which is very convenient when you have small, medium, and large companies. Figure 2 presents a parallel between the two types of frontiers mentioned.

Based on the concept of frontier (CRS or VRS) and control (inputs or outputs), there are different DEA models to be implemented. Among the most applied are the CCR-I, CCR-O, BCC-I and BCC-O models [10]. The first two were developed by Charnes, Cooper, and Rhodes [8] and operate under a CRS constant return scale, and the last two were developed by Banker, Charnes and Cooper in 1984 [11], which operate under a VRS variable return scale. Figure 3 shows two of the best-known DEA models.

One of the benefits of the application of DEA is the technical demonstration that the concepts of productivity and production are directly related. The result of measuring productivity is conditioned by the production

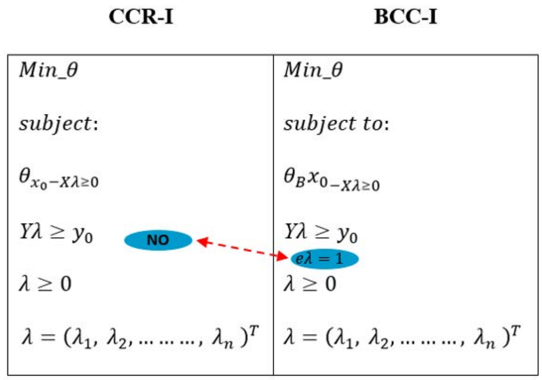

Figure 2 Efficiency frontiers [9]

function and the methods with which efficient production processes are obtained [13, 14]. Successful cases of DEA application describe how the best result in efficiency is the product of variables strengthened from the improvement of the production function, either through technological renewal, technical training of operational personnel, the closing of gaps in some step of the TPM total productive maintenance program or physical modifications of the plant that resulted in shorter cycle times. [15]

[16] presents the results of a study carried out in seven high-level private clinics in the state of Zulia (Venezuela) on measuring productivity using methods based on the production function and boundary analysis with DEA. The multiple linear regression analysis shows that the production function of the best clinic is positively related to the labor and supply factors, but that as the capital factor increases, production decreases. The supply parameter turns out to be the most important in absolute value. Regarding the non-parametric analysis, the production obtained or output analysis with the available resources, the clinics are efficient given that they are close to the frontier, except for one clinic. The input analysis or input productivity indicates the number of resources the company could reduce to obtain the same results, coinciding with the parametric analysis in which a clinic is the one that is furthest from the level of efficiency.

2.3 Value-added productivity measurement VAPM

By relating profitability to productivity, the VAPM value-added productivity measurement model seeks to measure the wealth generated by the performance of the main activity of companies, in such a way that it is complemented by regulatory financial indicators [17].
The methodology for calculating net value-added productivity is based on the measure, evaluate, plan, and implement cycle [18], and each of these stages

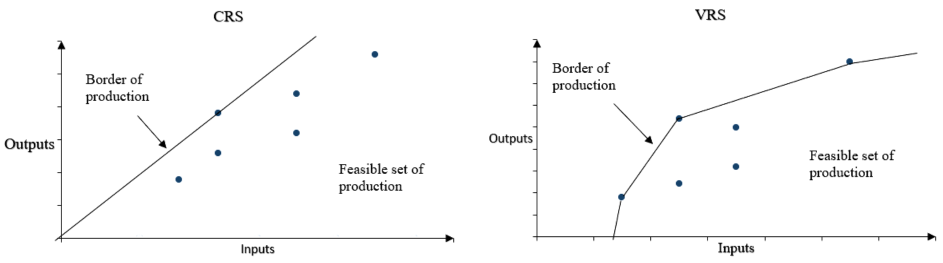

Figure 3 Mathematical difference between Linear programming models [12]

requires the development of several consecutive activities required by the model. Stage 1 contains activities 1, 2, and 3.

- Activity 1: establishment of financial statements and calculation of added value. *Financial statements:* The person in charge must obtain the financial statements (income statement, balance sheet, cash flow, general expenses, etc.) of the company in accordance with the International Accounting Standards IAS, which will allow the results to be comparable and allow proper decision making.
  Calculation of added value: calculate the added value with Equation 4.

$$VA = \text{ Net Sales } - \text{ third party purchases } + \text{ Stock changes }, VA = V - G + C(I) \quad (4)$$

- Activity 2: calculation and analysis of the productivity indicators of added value. *Indicators of added value:* they quantify the performance of the company and, therefore, support business strategies. In this step, the indicators of net margin, value/added index, capital participation, sales per employee, salary per employee, labor productivity, labor distribution index, net profit before taxes per employee, the contribution of personnel costs in the added value, and others that are needed in the process should be used [18].

  Calculation of added value indicators: For practical purposes of the development of this research, the following are considered:
  Added value index: it measures how much value added is generated per unit of operating income. It is important because it allows analyzing how much of the operating income contributes to the added value of the company, just as it provides information on income per person. It is related to production efficiency (Equation 5), and the result expresses the percentage of added value generated by operating income [18].

$$\text{Added value index } = \text{ Added value } / \text{ Operational income } IVA = VA/IO \quad (5)$$

Capital participation: This index shows the distribution of added value among its own capital, namely, the distribution between workers and management. Also, it relates the productivity of capital with profitability. When calculating this indicator (Equation 6), care must be taken when analyzing the scope of the effect on profitability, since it is about seeing the percentage of real value added that capital contributes to the company's own activity before taxes or after reservations [18].

$$\text{Capital participation index } = \text{ Period utility/Added value} \quad (6)$$

Contribution of personnel costs in the added value: Its result represents the number of times that the added value is generated in relation to the personnel cost, that is to say, the speed at which the personnel cost generates added value. This indicator (Equation (7)) is the productivity by the value of the personnel cos. It represents the performance of the productivity of the added value of the salary earned in the company [18].

$$\text{Contribution of personnel costs in the added value } VA = \text{ Added value } / \text{ Personnel cost} \quad (7)$$

Labor Distribution Index or relative participation of labor: Unlike the previous one, this indicator refers to the percentage of personnel costs in value added (Equation (8)); in other words, how much value added is attributable to personnel costs. Personnel costs refer to factors of production, capital, and labor.

$$\text{Labor productivity } = \text{ Personnel cost } / \text{ Added value} \quad (8)$$

Labor productivity: this measure aims to calculate the amount of added value generated by a worker (Equation 9). It is considered an important indicator for compliance with the principles of the Centro de Japan's Productivity Center (JPC) since it shows the achievement of the productivity of each employee according to the motivation, the workplace, the remuneration, and other factors they have in the company.

$$\text{Labor productivity } = \text{ Added value } / \text{ Employee numbers}* \quad (9)$$

Includes all independent collaborators of the type of contract and position level
Productivity of capital in equipment and machinery: This index is related to the efficiency of investment in machinery, buildings, and equipment, and calculates the

productivity in the effective use of these fixed assets in the generation of added value (Equation 10) [18]. It also establishes how much of the added value is generated by the investment in this type of element.

$$Productivity of the capital: Added value/Tangible fixed assets \quad (10)$$

Equipment utilization rate: With this indicator (Equation 11), the contribution to sales of fixed assets in the long term is measured [17].

$$Equipment utilization = Total income/Tangible fixed assets \quad (11)$$

- *Activity 3*. Calculation and analysis of productivity indices: After obtaining the necessary financial information and calculating the indicators that are well considered, we proceed to the analysis of the results and the determination of the causes of increase, decrease, or stability of each one.
- *Stage 2* evaluation: it includes the activities of profitability analysis, applying the planned value-added indices to calculate the optimal labor force, comparing the planned and obtained value-added indices, and reassessing and checking the current situation [17].
- *Stage 3* planning for productivity improvement: in accordance with what was obtained in Stage 2, we proceed with the activities of preparing improvement alternatives, examining the improvement alternatives, comparing them, determining a possible alternative, and implementing the best improvement alternative [17].
- *Stage 4* Measurement of productivity: after the implementation, the activity of measuring the results of the improvement plan is carried out [10]. In the methodology of the CyTA National Productivity Center for calculating value-added productivity, value productivity refers to the economic value created through a series of activities developed in the company. The National Productivity Center states that:

The value created in a company can be compared with that of another company and between industrial sectors, despite their differences, since changes in the body of the product or services are incorporated into the value of the goods or services. The value of these changes is revealed by the recognition that the consumer recognizes through the price he pays [19].

The value created is the difference between sales, materials, and services purchased [19]. That is to say, the generation of wealth of a company occurs after subtracting from its sales the generation of wealth of other companies, when it contracts processes or services with them or with other people. Figure 4 illustrates the concept of added value and the differences between this concept and conventional accounting based on the income statement. The difference is that for added value, wages are not an operating cost, but rather a cooperation factor to increase wealth; furthermore, depreciation is not a cash flow generator or a positive factor, as in the case of cost accounting.

According to the National Productivity Center, the measurement of added value at the company level can be achieved by the addition method or the subtraction method:

- *Subtraction method:* When dealing with the difference between the concept of value added VA and utility, it is evident that the value added (Equation (12) can be calculated by subtracting the purchases M from the value of sales V, the payments for all services S and the other payments to third parties G [12].

$$VA = V - M - S - G \quad (12)$$

Also, production (P) is equal to sales adjusted for change in inventories (DInv). Also, production (P) is equal to sales adjusted for change in inventories (DInv). If inventories increase in a given year, it is because production was greater than sales volume in that year and, conversely, if inventories decrease, it is because production was lower than sales (Equation 13) [19].

$$VA = P \pm D\,\mathrm{Inv} - M - S - G \quad (13)$$

- *Addition method:* In this way, VA is obtained from the sum of the values of its components (Equation (14): labor costs CL, depreciation D, leases A, interest paid I, taxes T, profits U [19].

$$VA* = CL + D + A + I + T + U \quad (14)$$

If the company makes donations, this social contribution must be added to obtain the added value. In the proposed methodology, CyTA uses a mixture of efficiency indicators with financial and commercial indicators, making the model more robust.

[20] state that there are factors that have influenced the improvement of the productivity of companies in Bogotá and Colombia, "The liberalization and intensification of trade, technological innovation processes, the import of machinery and equipment, high-quality intermediate goods Quality leads firms to adopt new production methods and increase efficiency (p.21). However, they conclude that the study leaves great concerns due to the "marked differences between companies in most of the fundamental variables that are taken in the analysis and that are definitive when the levels of productivity and competitiveness are consolidated, fundamental variables in the management of the human talent" (p.22).

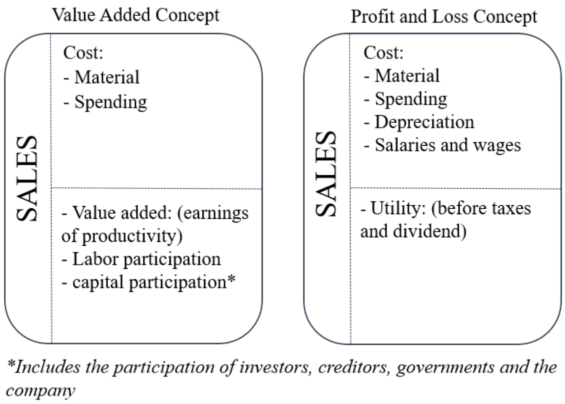

Figure 4 Calculation of productivity from costs vs added value [19]

2.4 Measurement of multifactorial productivity MP

The measurement of multifactorial productivity is a method based on indices, which seeks to avoid criticisms using other standard methods used more frequently to analyze the economic growth of countries [21].

Likewise, it is emphasized that, from the point of view of economists, a better result of productivity can be caused not only by the better use of a country's labor resources, but also by a factorial substitution [21]; that is to say, the best result of productivity is not necessarily achieved by better use of labor, but is enhanced by other factors that enter the process, for example, technological renewal [22].

The use of more capital in production processes is achieved with more significant investment in fixed assets, which is costly for companies. For this reason, and to achieve a joint measure of productivity, it is pertinent to consider a combination of the use of the human factor with its substitution by mechanized or automated force, which is beneficial for society [21].

Similarly, there is a relationship between the concept of multifactorial productivity and technological change [23], which generates neutral displacements in the production function that, over time, cause accumulated displacements; however, some technology assumptions (optimizing behavior of producers, constant returns to scale, and competitive markets) must be kept in mind; In addition, the measurement of changes requires simple information extracted from the operation and accounting [21]. In [23], the change in the production function can be measured as the difference between the growth rate of output and the (combined) growth rate of factor inputs, each weighted by its respective income share. This model was the beginning of what is known as growth accounting. Solow suggested using Divisa-type index numbers, which consist of considering the time variable continuously in the measurement of technological change, a subject that was expanded later by [24]. In the Solow method, it is difficult to identify which part of the residual occurs systematically and which is generated by measurement deviations; namely, really, how much contribution the capital invested in fixed assets has in obtaining greater productivity [21]. Besides, [24] emphasizes that the most well-known biases are non-observance of the existence of constant returns to scale, which allows the contribution of each factor to be adjusted to unity. Another bias is the value of marginal productivity, which contributes to the relative participation of each factor to the product obtained and the assumption that technological renewal does not affect the marginal productivity of each factor differently.

From the Solow residual model, we arrive at the multifactorial productivity measurement approach based on statistical information in discrete time since it is not possible to always have all the information available, contrary to the initial model that considers time as a continuous variable [21]. In the same way, the author states that the main indices for the measurement of multifactorial productivity are related to quantity and price indices, which are mainly used in the most representative case of multi-producer companies when there are several products and various inputs.

The multifactorial productivity measurement model presents implicit difficulties in its measurement, which are of a microeconomic nature and are related in most cases to the absence of micro-information for long periods, which makes the model unfeasible in the long run. From a theoretical point of view, the model appears to be robust; However, from a practical and real point of view, the difficulty of its implementation is evident.

However, increases in multifactorial productivity are considered broadly, including the effect of technological change, expected and abnormal profits, and changes in the efficiency conditions of producers, converting the model into one of aggregate variables [25]."Multifactorial productivity changes result from numerous events and factors that occur simultaneously at all times" [21].

Multifactor productivity indicators help differentiate the direct contributions to the growth of the factors of labor and capital, intermediate goods, and technology as an important tool to review past growth patterns and analyze the potential for future economic growth [26]. A different technique for measuring multifactor productivity is growth accounting "This allows the growth of output to be decomposed into the contributions of the production factors used (labor and capital) and the growth of total factor productivity" [27]. This methodology compared the economic growth in Spain, some countries in the European Union and the United States between 2000 and 2015.

2.5 Neoclassical productivity and marxist version NP

Orthodox economics considers productivity as labor productivity, where the relationship occurs between the product and a single factor of production, labor; that is to say, productivity is partial, contrary to neoclassical economics, but with a Marxist orientation [28].

This approach assumes with some certainty that the means of production are equally productive as work, increasing productivity, given that an improvement in the means of production used implies greater efficiency in production [29].

In the neoclassical version of productivity, capital as a product of the capitalist's virtue can be deployed in various factors, resulting in total factor productivity. According to this vision, productivity results from applying a multitude of factors: land, work, means of production, organizational capacity, technology, etc. [28].

However, since not all factors can be measured, Solow's multifactorial productivity measurement is used in the neoclassical interpretation of productivity, in which different factors are calculated by combining production functions and obtaining very high correlation values, whose residuals were used by Solow to correct the regression model. In the Marxist version of productivity:
The idea suggested by Marx is that productivity is the reciprocal of value, of the abstract labor that is socially necessary for the production of the different commodities in a basket of commodities... socially necessary means, first of all, that the labor expended in the production of each goods it is both direct and indirect labor. Thus, the efficiencies with which the different goods are produced are interrelated [28].

In the Marxist vision of abstract labor, merchandise is produced by merchandise since human labor is merchandise. This implies that an increase in production efficiency affects the manufacture of other products because, according to Marx, each merchandise is the result of the application of a part of social work and not only individual work [28], which can be mathematically expressed with Equation (15).

$$M = L(I - A)^{-1} \tag{15}$$

M= MA+L
MA = value of means of production
L = value of direct labor
M= Merchandise
[30] attempts to use the determinant of the matrices obtained in modern physics research to explain an interaction of classical productive factors and their impact on the economy of different countries. The application of the determinant focused on analyzing the location of 11 countries in relation to their productive factors. The example concludes that Japan and the United States have a dominant position with respect to other countries. However, Canada and Finland have a high value in the determinant of the capital and labor factors. "The classification with respect to the quantitative measure on the relationship between productive factors shows a better level in countries with high income compared to countries with low-income levels" (p.31).

2.6 Measurement of productivity under the influence of human factors PHF

The influence of the human factor is a fundamental variable in the results of the productivity indicator and the organizational performance [31–34], and [35]. Productivity is affected by various factors that have been studied in different areas of knowledge, in addition to being objectively described in this document; likewise, the behavior and characteristics of the individual and the collective affect the result of productivity [36]. For this reason, the human factor is one of the most difficult to identify and quantify since it is immersed in other psychological and psychosocial factors that determine it.

Regardless of the level of technological innovation that the organization has, the human factor is always present in productive activity since people perform functions and tasks individually. Still, in order to achieve organizational goals, they are necessarily interrelated in groups acting in social collectives [36, 37]. Psychological and psychosocial factors can be analyzed from individual, group, or organizational approaches [38].

As stated before, measuring productivity from the human factor is a complexly arduous task and, although subjective methods (Among the subjective methods for measuring productivity are the Likert scale, Delphi, multifactorial analysis, and confirmatory analysis) that include multidimensional and multifactorial scales have been used repeatedly, they are still not accepted from the point of view of reliability. However, the structural equations method searches for the best model from the comparisons between causal relationships of variables and a construct; in this case, the variable is the factors associated with the human factor, and the construct is productivity [38]. Likewise, it is a non-physical, abstract concept; they are hypothetical constructions that we elaborate to explain the observable variables [39].

Regarding the human factors that influence the measurement of productivity and according to the theoretical review, the investigations of [38–44] and [45] there is a classification of criteria associated with the human factor from the individual, group and organizational dimensions:

- Individual factors: in this category, the criteria are related to the individual's psychological processes or internal aspects of the person, how they perceive what is happening and how they react to environmental stimuli, observable variables: absenteeism, internalization of objectives, participation, motivation, job satisfaction [38].
- Group factors: the variables are related to the psychosocial processes that individuals experience when they interact or socialize with others in groups with a common objective, observable variables: recreation, cohesion, morale, and conflict [38].
- Organizational factors: the criteria are in accordance with the important activities of the company that affect the performance of the individual and of the groups; observable variables: interpersonal skills of management, flexibility, emphasis on achievement, information and communication management, wages and salaries, training and development, accident rate and quality [38].

Productivity is a function of the organization's goals as a result of people's management of available resources and the decisions they make. The observable criteria stand out: production, growth, and efficiency [38]. Expressed another way, when people strive to optimize organizational resources and staff perform effectively, the achievement of strategic plans is facilitated.

[46] state that the main causes for productivity not improving in Mexico are conditioned by decisions made in this regard in the past. The workforce in Mexico is largely unable to escape informality. Furthermore, low schooling and lack of skills and qualifications mean that people must stay in the informal sector. Likewise, formalized entrepreneurs do not find government incentives, which, in the long run, ends in a decrease in the aggregate productivity of the economy. These causes are linked to the pronounced regional social gaps, given that, in Mexico, there are more prosperous states and others in which poverty grows day by day.

2.7 Measurement of productivity in teleworking PTW

In general, the term telework is made up of two words: tele-work, which indicates that the person necessarily works and does so with the help of information and communication technologies (ICT), and that the tasks performed are carried out remotely [47]. Teleworking is expressed with the mathematical Equation 16.

$$\text{Teleworking} = \text{Work} + \text{Distance} + \text{Intensive use of ICTs} \tag{16}$$

This equation is an option to quantify the associated variables; the total cost of teleworking is obtained by assigning an economic value to each variable. It is also easy to establish a time unit for the variables to compare the results against other forms of work.
Similarly, it states that teleworking occurs when salaried workers carry out all or part (regularly or occasionally) of their work outside the usual site of their activity, generally from home, using Information and Communication Technologies (p.7) [48], Namely, in the teleworking the physical contact with other collaborators is replaced through the mediation of ICT.

Now, teleworking is a work arrangement where employees perform full or part-time work outside their workplace, usually through electronic means. Under optimal conditions, teleworking has positive effects on the productivity of companies (p.1) [49].
Teleworking is an application of the themes to business environments< it implies the employment relationship for its own or for that of others, considering in the same way the home work contract where the provision of the activity is carried out at the worker's home, or in a place freely chosen by the latter without the supervision of the employer, and using telematic means provided mainly by the contracting company. In this sense, teleworking makes it possible to send the work to the worker; in the same way, this modality admits the practice of a wide range of professional activities that can be carried out full or part/time.

These various places can be community telecentres, satellite offices, neighborhood work centers, call centers, offshore telecommuting, home telecommuting, office telecommuting, flexible office telecommuting, home office telecommuting, home and office mobile telecommuting, and used by freelance or self-employed, and business teleworkers [47, 48] and [50]. Further readings about this topic can be found at [47, 48, 50, 51] and [52].

Due to the above, the quality-of-life index of the inhabitants increases, representing an improvement at the microeconomic level that could be generated by the growth of business competitiveness, which in turn is favored by the increase in productivity. This business growth makes organizations more agile and flexible as a result of people being better prepared, and developing skills in managing and mastering new technologies, which allows teleworkers to interact more quickly in external environments, taking advantage of the information obtained for business purposes.

The benefits of teleworking are associated with its objectives, but the comfort it provides is the modality that makes people acquire a high level of commitment, responsibility, and ethics, as well as being creative, innovative, and technically competent in their profession or trade and, most importantly in ICT, who choose to carry out their work in this way [47, 48, 50, 51] and [52].

In teleworking, people obtain greater productivity, associated with the sense of freedom in carrying out activities and the opportunity to choose what to do and in which projects to participate and that in companies' productivity is higher "because teleworking is generally done by assigning jobs by objectives" [52]. I if, in addition, the advantages of teleworking are associated with saving and maximizing the performance of resources, then teleworking must be considered when measuring productivity.

For some organizations, teleworking not only reduces operating costs but also benefits the company in economic terms [49]; in addition, teleworkers are more satisfied with this modality and have less stress [53]. Other benefits of the application of the work are summarized and shown in Table 1 [53].

However, teleworking has disadvantages, negative consequences, and difficulties in its implementation. The risks in teleworking are the same as in traditional locations since the houses were not built to house manufacturing work, the cost of equipping the physical space must be assumed in its vast majority by the teleworker, people can develop stress due to isolation, anxiety, depression, and job insecurity, leading to decreased performance and deteriorating quality of life [50].

Regarding work performance, the studies show that the performance increase in teleworking is slightly higher than in the traditional modality, obtaining an individual additional of between 3% and 9%. But this slight increase is apparently due to the fact that in teleworking, an average of 4 hours a week is worked more than in the traditional way [50, 53]. Not all jobs are susceptible to this modality. In the research by professors Golden and Gajendran, it was found that teleworking is more recommended for jobs that involve a high level of concentration and less interaction with others [54].

In the field triangulation process for the evaluation of the variables, the professionals who responded to the research stated that teleworking substantially reduces the variable costs of workers, and increases productivity and the time dedicated to work. Likewise, the work modality was considered a highly relevant variable [55].

2.8 Structural equation model SEM

The method of causal relationships is used in empirical research in which it is necessary to decipher the relationships between non-physical variables, over which there is no greater detail or control [36, 56, 57] and [58]. In the social sciences, the methodology of causal relationships is the set of strategies and techniques that allow events or events to be explained, contrasting them empirically and whose purpose is to study the effect of the variables examined as causes on others considered as effects [59].

To measure linear causal relationships, the structural equations model is used; that is to say, causal theories can be statistically measured using estimators such as covariance and correlation to affirm or reject a hypothesis of the causal model [38, 57–59] and [60].

Through the simultaneous analysis of the entire set of variables, the theoretical model proposed by the researcher is subjected to statistical contrast, with the aim of verifying to what degree it is consistent with the data obtained empirically (p.122) [38]. A structural model is made up of the structural Equation 17 and a path graph (Figure 5).

$$\eta = B\eta + \Gamma\xi + \zeta \tag{17}$$

Where η = endogenous latent variable that the model tries to explain, β = coefficients (βij) that relate the endogenous latent variables to each other, and Υ = coefficients (γij) that describe the exogenous latent variables (ξ) with the endogenous ones (η) that are to be explained, ξ exogenous latent variables or predictor variables, and Φ error or disturbance terms, indicate that the endogenous variables are not predicted in the structural equations.

It should be borne in mind that in the structural equations model, the effects of the variables can be direct, indirect,

Table 1 Benefits of teleworking [53]

Economic	Social	Environmental
Reduction of transportation, clothing, and food costs for post-teleworkers	Job opportunities for vulnerable population	Reduction in the circulation of cars (reduction in air pollution and energy savings)
Reduced fixed costs	Reduced fixed costs	Reduction in the use of paper.
Reduction in staff turnover	Employment stability	
Productivity improvement	Reconciliation between work and family life	
Decrease in work absenteeism	Promotion of labor insertion in the rural sector	
Reduction of travel costs and expenses	Flexibility in schedules	

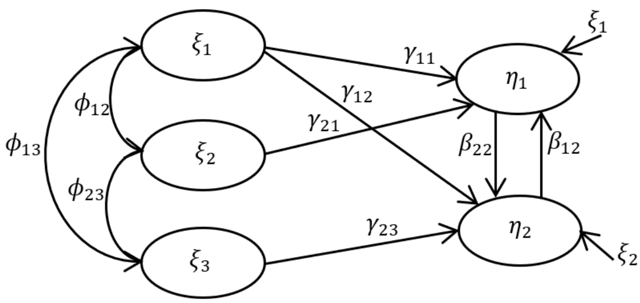

Figure 5 Path graph of a structural model [38]

and total. They are direct when a direct relationship between two variables is indicated and indirect because the relationship between two variables is generated from one or more mediating or intermediate variables. They are total because they constitute the sum of the direct and indirect effects of the variables [38].

2.9 Stochastic frontier analysis SFA

Statistical methods are used to calculate organizational efficiency, which considers that the resulting deviations in the process are attributed to statistical error [61, 62]. "Many economic models admit the assumption that all companies are efficient, the reality that can be observed in practice usually suggests that there are quite a few inefficiencies in this world" [61]. Differences in the inefficiencies of complex systems may arise due to interculturality, the different management practices implemented in companies, or staggered levels of technological sophistication" [61].

The SFA approach recognizes that all DMUs may or may not be efficient, depending on the statistical analysis applied [61, 63]. This process checks the data and, at the same time, allows the statistical error to be calculated. The SFA approach offers a picture in which the ratios of production factors can also be estimated "as a conditional average (of outputs given inputs and other factors, in the case of production function), but the total deviation from the regression curve is decomposed into two terms - noise and statistical inefficiency" [61]. The SFA approach is a paradigm that shares the postulates of traditional theories. However, it differs because it decomposes the statistical error into several aspects, one of which does not come from process deviations.

Likewise, "It is important to note that the SFA approach also allows the inefficiency term to be statistically insignificant, if the data suggests so, thus encompassing the classical approach with a naive approach" [61]. Furthermore, the SFA approach "also encompasses the other extreme where one assumes no statistical noise and all deviations are treated as frontier inefficiency," [61], behaving like a traditional measurement model.

Mathematically, SFA allows us to estimate the global inefficiency of a system by comparing it with each DMU. It also contributes to the context by analyzing the causes of productive inefficiency and the variation in productivity to subsequently suggest important ideas to reduce inefficiency. The mathematical model that represents SFA can be seen in Equation 18

$$\begin{aligned} yi = m(xi;\beta) - ui \\ + vi = m(xi;\beta) + \varepsilon i \end{aligned} \tag{18}$$

$m(xi;\beta)$ capture the production border or DMU; xi is the input vector
ui capture the inefficiency
vi capture the stochastic shocks
SFA is an innovative approach to traditional productivity measurement models; it is adapted according to the quality of the data to calculate the value of inefficiency/efficiency, taking into account irregular process deviations and generated noise, or taking a part at a time of the total deviation, to run your tests. This is because "the main difference between a standard production function setup and the SFM is the presence of two distinct error terms in the model" [61].

2.10 Transdisciplinary model of productivity based on exact, social, and human variables TMP

The formulation of the model required a compilation of transdisciplinary variables chosen through an investigative process applied to various sources of knowledge. A part of the variables comes from the literature review of the theoretical framework and state of the art related to the topics: complexity, transdisciplinary, productivity, and the models to measure it, from exact, social, and human disciplines [64].

A second source of variables is compiled from reports from private and governmental organizations on the performance of organizations and labor productivity in a region or country, and a third source of variables is the knowledge and professional experience of people trained in social, humanistic areas, industrial engineering, and related careers [64].

Other qualitative and quantitative variables were extracted from the technical operation of companies in the real sector, the results of indicators of productivity, effectiveness, quality, level of customer satisfaction, degree of standardization of processes, access to the financial sector, logistics, and environment, the behavior of its collaborators and the barriers identified for the increase of competitiveness. Some social and human factors were chosen, taking the needs of society as criteria, as well as the current problems. In the same way, the exact transdisciplinary variables were grouped by the relationship of processes or resources for better understanding, also finding several variables in one category [64].

The qualification of the variables in relevance, pertinence and importance was obtained through triangulation in the field carried out with three categories of professionals: a technical instrument for professionals in the social and human sciences, a second questionnaire for entrepreneurs, and mid- or high-level employees of industrial companies and a third group made up of industrial researchers and engineers or careers related to the topic under study. The complete methodology for obtaining the variables and their qualification process can be seen in [55, 64].

Transdiscipline is the innovative and integrating foundation of variables typical of the exact, social, and human sciences that lead to a new way of thinking, measuring, and monitoring productivity. The summary of the conglomerate of variables can be seen in Table 2.

Each category contains variables classified as favorable or limiting, which are integrated into the formulation of the model, identifying the dimensions that comprise it. The transdiscipline comes from traditional disciplines combined with other less conventional ones that emerge in society, giving the model the characteristic of integrality in continuous intervals, reaching full coverage of the elements. It is a complex model because it concentrates on various postulates, avoiding falling into the rigorous linearity of the exact sciences, and trying to converge a multiplicity of options.

Figure 6 outlines the general plan of activities for the formulation of the Transdisciplinary model of productivity measurement. The elements of each stage are developed in sequential order following the methodology proposed in scientific research.
Table 2 summarizes the fulfillment of two of the research objectives: to determine the necessary variables in measuring productivity in companies in the industrial sector, both from the exact sciences and from Complexity, and to integrate the variables determined in the development of a productivity measurement model. For this, the development of several stages was necessary, including a bibliometric analysis and triangulation in the field for the evaluation of the variables.

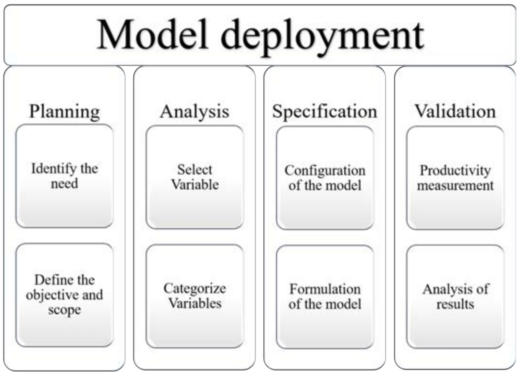

Figure 6 Transdisciplinary model stages of productivity [64]

The Transdisciplinary model of productivity measurement is made up of four categories of elements, three of which are conglomerates of variables, and one corresponds to a corrective or smoothing factor for deviations caused by subjectivity and randomness generated in the process. The model is also characterized by the contrast of variables since, in each category, they add or subtract according to the goodness or weakness they possess, leaving the possibility open for inserting other incident variables in the real sector; likewise, the model in its flexibility and dynamism allows us to dispense with some measures that have no impact on productivity at any given time. The relative weight of the variables within the clusters is

Table 2 Conglomerate summary of transdisciplinary model variables [64]

Exact variables	Categories	Subcategories	Social and human factors	Categories	Subcategories
Processes	10	18	Individual	15	40
Plant and environment	2	2			
Machinery, equipment, and tools	3	4	Group	13	52
Workforce	5	25			
Financial	6	8	New variables	2	4
Company/ Organization	11	29			
Human/Society	6	21	Subtotal	30	96
State/Government	6	17			
New variables	9	9	Total	88	229
Subtotal	58	133			

established based on the relevance they present in the processes, guaranteeing the Complexity of the same [64].

Figure 7 shows the characteristics that intervene in the formulation of the model, highlighting the variables that obtained the highest scores in the application of the instruments in the real field. It must be emphasized that no variable is discarded due to the qualification obtained, only that the most relevant are those used to exemplify the formulation of the model, but since it is a dynamic model, a company may use the variables that affect it in its particular case within the Transdisciplinary categories that the model has. The formulation of the model allows incorporating in the main categories any parameter that the company considers is not contemplated in the general model, but that affects efficiency.

3. Contrast and discussion between models

The philosophy of continuous improvement assumes that the way of life in the work, social, and family environment deserves to be constantly improved since the improvements obtained in performance standards lead to progress in quality and productivity [64]. The most advanced productivity strategies allow us to observe that the participation of workers must be generated and stimulated due to the great potential of knowledge and daily experiences that they have developed in the work process [64].

In contrast to the above, traditional models use a measurement of partial productivity based on exact variables, whose figures are discrete or continuous values resulting from the action of internal processes, using one, two, or several variables, which occurs in the measurement of partial, total, relative, DEA, VAPM, multifactorial productivity, SEM and SFA. The calculation of the indicator is static; it represents the photograph of a certain moment of the situation, and the numerical percentages indicate how effectively the execution of the business is being developed to make decisions later; however, it is how companies deploy the activities of the strategic plan.

VAPM, in addition to having the characteristics of traditional models, calculates the value of contribution per resource to the organization's wealth, an essential aspect in the investment debate; that is to say, VAPM provides information to approve or subtract a resource's budget based on its historical behavior. Similarly, the multifactorial analysis conceives the productivity of a country from the economic approach, considering labor and factorial substitution, especially in technological investment. It is a very significant combination of the workforce and technology. This model is advantageous for the Government in the establishment of taxes.

On the other hand, the neoclassical and Marxist version of productivity is based on the fact that it is generated by several factors called merchandise that, when combined, project a total value of productivity as a logical consequence of the operation of a system. In addition, it takes into account the Solow model to correct deviations or obtain measurements of factors that, according to the postulates, are not feasible to measure.

Now, the social and human sciences use qualitative technical instruments to measure people's job performance; however, the results are used to decide the continuity of a collaborator in his functions or to develop some training to minimize the risk factor found. These so-called categorical models have no impact on the operations area; in most cases, both areas do not share information or simply the speed of the tasks does not allow it, making these results partial, following the traditional line.

With Covid-19, the modalities of work became more flexible, which allowed part of the workforce to work from other physical environments with the mediation of ICTs, an important aspect that has been included in the measurement of productivity in recent studies, which

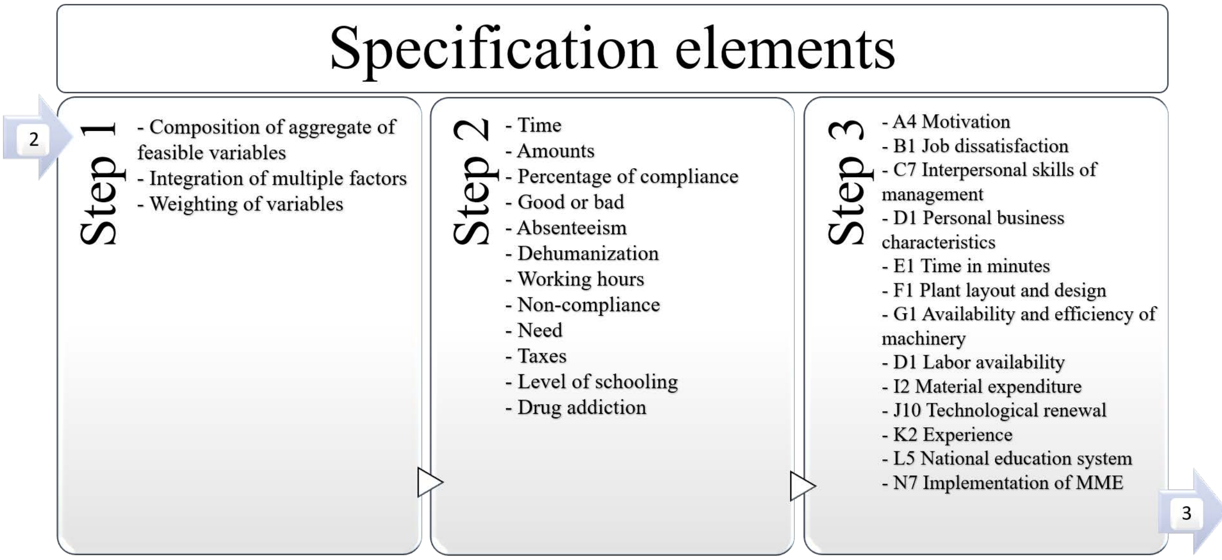

Figure 7 Specification stage [64]

outlines the advantages and disadvantages of the model, but teleworking cannot be considered as a model for measuring productivity itself, it is a form of work that helps or not in productivity and therefore must be taken into account for complete measurement of productivity.

As a corollary to the above, in productivity, elements derived from the systemic dynamics of an organization with the environment must be included, integrating internal elements directly related to the company and coupling other exogenous factors. Analyzed in this way, productivity becomes an indicator of an effective tool for business improvement, which allows the demonstration of the dynamism and flexibility of a system that responds to permanent changes because of the movements of the world that require immediate attention, representing the transdisciplinary model. Table 3 shows a comparison between the models. The characteristics are related to advantages, disadvantages, and important aspects of the analyzed models. The rating assigned corresponds to commonly used scales for each aspect. In this case, 15 characteristics considered important within the research are proposed. However, as it is a multidimensional study, new characteristics of interest emerge at any time.

4. Conclusions

Theoretical aspects found in the bibliographic search about the performance of organizational resources indicate that the technical elements associated with one or another model affect the final result of productivity measurement and that the use of any model is discretionary on the part of the strategic actors.

The inclination of academic researchers and experts in areas such as engineering, statistics, and economics to promote the use of a model associated with their professional training is notorious, while professionals in social and human areas are focused on the implementation of partially diagnostic tools related to the occupation and performance of individuals in a specific context.

Entrepreneurs, for their part, use the traditional productivity measurement method, which is partial, easy to implement, and requires less effort to obtain and maintain data and information. Likewise, it is compatible with union and government indicators.

Traditional productivity measurement models are developed from mathematical formulations; however, they have not been integrated with research results of a social nature. This has generated a duplication of efforts in training from various disciplines, without the achievement of a joint study that allows a comprehensive measurement of productivity from Transdiscipline. Therefore, for the integral measurement of productivity, in addition to exact quantitative variables, the concurrence of variables that come from the human and social sciences is required. The active participation of the academic sector in its elaboration must also be present as a fundamental element, in such a way that with the intervention of various disciplines of knowledge, a systemic approach is obtained.

The most experienced researchers have shown that it is possible to include values associated with the human factor from the social sciences in the measurement of productivity using multifactor analysis, structural

Table 3 Conglomerate summary of transdisciplinary model variables [64]

	Productivity measurement process										
	Models	**TRP**	**DEA**	**VA**	**MP**	**NP**	**PHF**	**PTW**	**SEM**	**SFA**	**TMP**
Characteristics	Mathematical formulation	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes
	Implementation cost	Low	Low	Middle	Middle	Low	Low	Low	Low	Low	Middle
	Degree of complexity	Low	Middle	Middle	High	Low	Low	Low	Middle	Middle	High
	Ease of access to data and information	Easy	Easy	Middle	Middle	Low	Easy	Easy	Middle	Middle	Middle
	Type of software requiered	Basic	Basic	Intermediate	Intermediate	Basic	Basic	Basic	Intermediate	Intermediate	Tailor made
	Variable Category	Exact	Exact	Exact	Exact	Exact	Socials and Humans	Exact and Humans	Exact	Exact	Exact, social and Humans
	Knowledge and experience of the personnel who execute the process	Middle	High	High	High	Middle	Middle	Middle	High	High	High
	Model in use	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
	Compatible with Government indicators	Yes	No	Yes	Yes	No	No	Partially	No	No	Yes
	Reliability of results	Middle	Middle	Middle	Middle	Low	Low	Low	Middle	Middle	High
	Requires other tools to validate results	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
	Innovative	No	No	No	No	No	No	No	No	Yes	Yes
	Flexible	No	No	No	No	No	No	Yes	No	Middle	Yes
	Dynamic	No	No	No	No	No	No	No	No	No	Yes
	Integrates several disciplines	No	No	No	No	No	Yes	Yes	No	No	Yes

Total: Numbers 1 to 10 correspond to the models in the order they appear in this document.

equations, and software. This allows us to conclude that it is possible to formulate a new productivity model integrated by multiple variables from various disciplines using multivariate analysis, structural equations, and other mathematical and physical techniques.

The referenced authors agree that increased productivity enhances the improvement of organizational competitiveness and economic growth. The intended transdisciplinary model is integrative, innovative, and flexible and seeks to generate measurable positive impacts on the productivity and competitiveness of companies and regions. Consequently, it shares the same objectives. To a large extent, experts believe that productivity cannot be measured exclusively using exact variables; including of other multidisciplinary factors is necessary. They also express that obtaining a transdisciplinary model based on exact, social, and human variables is complex. However, current scientific developments in information technologies offer broad possibilities in tools for the development of software that would represent the new transdisciplinary model of productivity, making it viable.

The contrasted models have elements that characterize them; they are more or less complex to a certain extent. Six of them have been fully validated in the business environment, and some continue to be used more strongly than others.

The bibliographic research, the documented cases, the world current affairs, and the simulation of the DEA data envelopment analysis and a categorical model that contemplates exact and soft variables in a company in the metal-mechanical sector for eight months, in which it was demonstrated that DEA is disturbed by the presence of a weak factor in its exact nature and that by measuring a categorical model consisting of exact variables and social and human factors, productivity increases [53]. They allow us to affirm that the transdisciplinary model is necessary because it reveals aspects of reality that must be measured in organizational performance; likewise, cooperation with existing techniques is essential, for measuring productivity as much as possible, which is evidence that the models do not exclude each other, on the contrary, they complement each other.

5. Declaration of competing interest

The authors declare that there are no significant competitive, financial, professional or personal interests that could interfere with the objective presentation of the complete work described in this article.

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7. Author contributions

Author 1 is the creator of the transdisciplinary model of productivity, as a contribution to her doctoral thesis. For their part, Author 2 and Author 3 contributed to the methodological support and the comparison of models.

8. Data availability statement

The authors confirm that data supporting the findings of this study are available in the article [and/or] its supplementary materials.

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