

MATHEMATICAL MODEL FOR THE INTEGRATED CALCULATION OF PRODUCTION, LOGISTICAL AND SERVICE CAPACITIES IN THE VALUE CHAIN

Igor Lopes Martínez, Ana Julia Acevedo Urquiaga, Yinef Pardillo Báez, José A. Acevedo Suárez, Martha I. Gómez Acosta

Zusammenfassung

Die Entwicklung des SCM (Supply Chain Management) schließt insbesondere die Kapazitätsorganisation für die operative und auch die strategische Gestaltung der Planung einer Versorgungskette ein. Das Problem kann der Kategorie des Maschinenbelegungsproblem aus dem Operations Research zugeordnet werden. Eine zweite Generalisierung wird aufbauend auf einem vorhandenen Rechenverfahren für die Kalkulation der Produktions-, Logistik- und Servicekapazitäten vorgestellt. Mit der Generalisierung können die einzelnen Prozesse separat untersucht werden. Die Kapazitäten der SCM-Prozesse werden durch die Größe der finalen Nachfrage nach Produkten und Dienstleistungen gemessen und in monetären Einheiten des Ertrags oder der Verluste dargestellt. Ein Fallbeispiel aus dem Fertigungsbereich von Aluminiumblechen erläutert die Vorgehensweise.

Key Words

Capacities, mathematical model, supply chain.

Abstract

The development of supply chain management includes the capacities coordination among the processes that integrate it, so much in the operative plan as in the strategic one. This problem could be allocated to the classic job shop scheduling problems of the Operations Research. In such direction, a second generalization of the calculation algorithm of the production, logistics and service capacities is formulated starting from the one reached previously by the own authors. With this generalization it is facilitated to carry out the calculations of capacity at the supply chain level and of each one of the processes. The generality's application is flexible to processes of production, transport, storage, administration and for service. The capacities of each process of the supply chain are expressed in the magnitudes of the final demand of products and services in the consumer, considering the losses and returns along the supply chain. A study case is presented to demonstrate the possibility of use in one field, but it is explained the possibility to use in different fields, from the production of aluminum carpentry to services related to medical equipments.

» I. INTRODUCTION

The authors summarize the prevalent insufficiency in the literature in the calculation of the capacities for multi-product and complex process network (Anaya 2007; Pérez 2010). Although it assumes the concept of APICS (APICS - The Association for Operations Management - American Production and Inventory Control Society) that the capacity is the "maximum rhythm of sustainable output that you can get with the normal specifications of the product, production mix, normal effort of manpower, plants and existent teams". It defines that when one gives a variety of products, the capacity can settle down in added terms by measure units to which it can reduce all the products (tons, cubic meters, etc.), recognizing that there are not always useful measurements. It outlines that in these cases the capacity is usually measured

in terms of input, that is to say, of the resources that are used, such as hour's machines, hour's man, tons of raw material and others.

For the coordination mechanisms of the supply chain, today is information sharing the capacity focus (Brikmann and Lang 2011). This coordination is effective when there has been a joint capacity measurement and planning of supply chain as strategic decision.

The objective of this article is to show the possibility of application of the proposed calculation method and the process associated with it in one of the different sectors applied, the one is the aluminum carpentry production in Cuba. One problem was that the decisions associated with the achievement of the customer demands in these sectors were made based on empiric studies and with the application of the

methodology it was possible to conclude about the relation between the demand and the actual capacity.

» II. MATERIALS AND METHODS

The current development of the integrated management of the supply chains is a current trend in agriculture development (Briz et. al. 2010) and requires that one of the variables that should be coordinated in the network of processes is that of capacity. These nets not only include production processes, but also transport, storage, service, administration, agriculture and others. In turn the practice indicates that the restrictive processes of the capacity of the supply chain are not always the productive ones. For such a reason it is demanded that the procedure of calculation of the capacities is comprehensive to all process type.

In such sense, Kunkel (2003) defines the 8 elements of the management of the supply chains: planning, information and communications technologies, alliances, inventory management, service guided by the customer, production guided to the customer, nets formation and supply management. In the concept of collaborative planning, seen as the integration of the systems of planning and control of the chain's partners, just as Winkler (2005) mentions it, it requires settling down a dialogue among the participants in the net on equal reference bases to be able to carry out an effective coordination of their capacities.

In equal form, of the pronouncements of Chopra and Meindl (2004) it is deduced the importance and the necessity from not only calculating the capacity in the processes of production, but also in the other types of processes that integrate the supply chain when exposing that "the facilities (production, warehouse) and their corresponding capacities to carry out their functions are a key driver of the acting of the supply chain in terms of responsibility and efficiency".

In the capacities calculation, it relies on the unitary time of prosecution. However in certain processes times are not determined for each product unit. Such is the case of the transport and the storage in that what is controlled is the cycle of an operation to transport or to store a quantity of products in a combined way. On the other hand, the emergence of the management at level of supply chains generates that the calculation and analysis of capacities should be carried out in two levels:

- At process level, taking as unit the operations.
- At supply chain level, taking as unit the process, which has been weakly treated in the literature (Acevedo and Hernández et al. 2001).

It is required that the procedure of calculation of the capacities is flexible to work in the two signal levels, since they should be supplemented in the management, although the detail grade is different in each one.

Although the initial algorithm contemplates in the calculation of the production capacities the structure of the demand, in certain cases some marketing approach should be introduced in the sense of prioritizing some products mainly when there is deficit of capacity and it is not possible to satisfy the total demand of all the products. In such a sense it is required to consider in the algorithm the restriction of guaranteeing at least in some products a minimum quantity.

In Supply Chain Management is essential that inter-firm links are the result of the integration and exchange of resources (i.e. human resources, physical resources, and other) (García 2010). Human and physical resources are determinants of the supply chain capacity.

» III. RESULTS AND DISCUSSION

In formulating the model HPPLAN (Günther and Tempelmaier 2005) it's structured a linear optimization model, but its starting point that the capacity of each process is known at each time interval. However, the magnitude of capacity depends on the mix of products or services offered on each coordinate process and this calculation is required throughout the value chain. Similarly pronounced Soret Los Santos to make balancing the

capabilities of a process chain, where is known the capacity of each process and a single product (Soret Los Santos 2010).

Other authors express the calculation of the capacity in units of time (Koether 2010), on this approach is required at each time to determine the workload that represents a particular demand, but it is difficult due to the dynamic variation of the structure of the demand, the consideration of losses and changes in the interrelationships between processes.

It therefore requires a method for calculating the capacity in the value chain focused on the final demand, considering a mixture of products and services, the diversity of processes (production, services, transportation, storage, agriculture, and others) that make up the value chain, the interrelationships between them and yield losses in each process.

Starting from the previous problem and studying different cases it is possible to arrive to the formulation of the system of equations that allows defining the second generalization of the calculation of the production capacities and services (Acevedo 2008). The transformations of the system of equations of the (1) to (5) they are defined from now on.

The system of equations that was formulated for first widespread calculation (Acevedo and Hernández et al. 1987) is the following one:

$b_j = \frac{F_j}{\sum_{i=1}^n T_{ij} * P_i}$	ww	(1)
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(coefficient – quantity of times is possible to make the demand in relation with the base time available)

$C_{ij} = b_j * P_i$	(Unit of measure of the process (UM))	(2)
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$C'_i = \min(C_{ij})$	for all j	(3)
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$C_i = C_{ij}$	for j = fundamental point	(4)
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$Kper_i = \frac{C_i - C'_i}{C_i}$	(%)	(5)
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where:

i	product number (i=1, 2, 3, ..., n)	C_j	production capacity of the i final product in the j operation in the analyzed period
j	operation number (j=1, 2, 3, ..., m)	C_i	production capacity of the i final product (UM)
F_j	base time of the j operation in the analyzed period (year, month or week)	C'_i	capacity in the restrictive point for the i product
T_{ij}	prosecution unitary time of the i final product in the j operation (time)	$Kper_i$	capacity loss coefficient of the i final product for existence of "bottle neck"
P_i	demand volume of the final product in the analyzed period (UM)	b_j	capacity coefficient for the calculation in the j process

In the generality of the cases it is possible to arrive to the unitary time of each operation or process starting from quantifying for observations or registrations the duration of the cycle of the operation or process when it is processed a quantity of products simultaneously, that is to say, a large size. Such it is the case of a process of transport in which the cycle is the sum of the time of location of the means of transport in the load point, the load, the movement of the load point to the destination point, the discharge in this and of the return if it is not that it is programmed

to carry out another load in the return. This cycle is executed to transport a load of certain quantity of physical units or tons as it is the case. Similar situation happens with the storage and agricultural processes, and even in some production processes. With this algorithm the program Capacidad11a.xls has been developed that it allows to work with a total of 100 products or groups of products and 40 processes or operations of the supply chain and it assures to calculate the capacities so much at process level as of the supply chain, embracing processes

of production, services, transport, agriculture, storage, administration, agriculture and others.

In the capacities management it is important to consider the costs associated to the same one with view to achieve alternative that propitiate a reduction of the same ones. In the signal program there are considered two elements of costs associated to the management of the capacities. They are:

$$T_{ij} = \frac{L_{ij}}{Q_{ij}} \quad \text{(time per lot or product)} \quad (6)$$

where:
 L_{ij} cycle of the operation or process j for the treatment of the product i with a lot size of Q_{ij} (time)

The equation (1) for the calculation of the b_j it transforms in this way:

$$b_j = \frac{F_j * N_j * A_j - \sum_{i=1}^n T_{ij} * PM_i * f_{ij}}{\sum_{i=1}^n T_{ij} * (P_i - PM_i) * f_{ij}} \quad \text{(coefficient)} \quad (7)$$

In the equation (7) the coefficient f_{ij} is the one which reveals the interrelations of the processes and operations of the material and productive flow that are given internally in a process and in the supply chain.

$$f_{ij} = \frac{r_{ij}}{g_{ij}} \quad \text{(coefficient)} \quad (8)$$

where:
 N_j efficiency index of the operation or process j (%)
 A_j quality acceptance index in the operation or process j (%)
 PM_i minimum production to assure of the final product or service I (UM)
 f_{ij} flow index of the product i for the process or operation j (coefficient – quantity of product needed to make one final unit of product)
 r_{ij} proportion of the final product i that should assure the process j (coefficient)
 g_{ij} consumption index of the intermediate product that it obtains the process j for each unit of the final product i on the net. (coefficient)

The equation (2) transforms contemplating the minimum production that should take place, since the algorithm it reserves a part of the bottom of time of all the processes to assure the minimum defined production according to the equation (7), being in the following way:

$$C_{ij} = b_j * P_i + PM_i \quad \text{(Unit of measure of the process (UM))} \quad (9)$$

The equations (3), (4) and (5) stay the same. In this way it is possible to adjust the algorithm of calculation of the production and service capacities to the current problem described previously.

■ *Capacities underuse cost.* It is calculated starting from considering the fixed costs of each process (depreciation, wages, contribution to the social security, tax on use of the work force, administration expenses, financial expenses, and others) affected by the percentage of capacities sub utilization in each process.

■ *Opportunity cost.* It is calculated starting from the unfulfilled demand by the capacities multiplied by the margin of contribution of each product and adjusted by a percentage that reflects the correlation between the losses of sales and the non readiness of the products for the clients that it should be determined experimentally in each case.

The total cost calculated as the previous sum of both is an indicator of the level of efficiency that contributes to the company or the supply chain the capacities management. In this way, the capacities management is integrated with the objectives of the logistics of improving the service to the client jointly with a reduction of the logistical costs.

» IV. APPLICATION CASE

Case: Calculation of the capacity of the production sector of the carpentry of aluminum.

The calculation and analysis of capabilities proposed in this paper has shown its effectiveness when applied to independent entities and even the processes underlying supply chains, but often there is a need for strategic analysis for the development or reorganization of a particular productive sector to ensure consistent draw and sustainable land policies.

For the purposes of the application of the calculation procedure of capabilities it is necessary to supplement the procedure with a set of steps that allow to methodologically homogenize the information of the various entities that make up the productive sector under study as shown in the Figure 1 below.

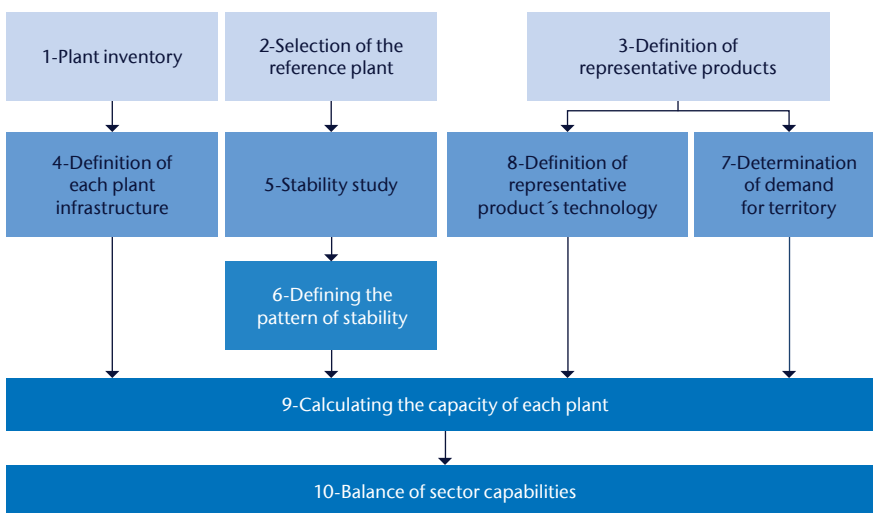


Fig. 1) Methodological framework for calculating the production capacity in a sector

The steps of the procedure applied are the followed:

1. Plant inventory

As a first step in calculating the capacity of a productive sector is required to perform the definition of all plants or facilities engaged in the production under consideration. Of each plant should be pointed the representative products it manufactures.

2. Selection of the reference plant

Of all existing plants should be selected which is considered more effective and representative from the standpoint of

organization and technology to take it as a reference in the study, if any of the existing plants meet the desired efficiency features it must conform a model plant to the study.

3. Definition of representative products

In a productive sector generally works with a wide variety of assortments, which can be produced by all plants or each plant can be committed to the production of certain assortment. It is then convenient to perform a process of definition of assortments representing the sector on the basis of which is homogenized the technological information that facilitates and standardizes the analysis and calculation of productive capacities in the sector.

Sometimes, it is not possible to define the representative product from the existing and is necessary to define an equivalent product through which it is

equipment and production areas available in each of the plants of the productive sector under study.

In the design of the information to obtain on the infrastructure available at each plant must be from a process of identifying the equipments and homogeneous groups of equipments participating or may participate in the production process and the level of equivalence between them.

5. Stability study

In the factory selected as a representative must be studied the stability of the production process, from analysis of monthly data output (in value) over a representative period (not less than one year). This value of stability must be taken as reference to set the minimum level of stability to calculate the production capacity of each plant and consequently set the pattern of stability to be followed in the study.

6. Defining the pattern of stability

With the results of the calculation of stability in the reference plant and the analysis of existing organizational level in the plants of the industry, the next step is to define the pattern of stability that determine the capacity of the productive sector under study or the level of stability which will aim to be achieved by each sector components plants.

7. Determination of demand for territory

The demand is a basic parameter for the balance of capability of a process and therefore a productive sector in the latter case it is important to determine the demand for each territory of which make up the geographic area to study, because this is the basic point for the reorganization of production capacities and the restructuring and downsizing of the campus industrial.

8. Definition of representative product's technology

For each Representative product is defined the set of operations or tasks to be performed to obtain the product and the procedure for implementing each one. The technology should be reflected in documents (technological letter, route sheet, flow chart) to facilitate the taking of information for the calculation of capacity. For each technological

possible to represent, according to the equivalences established, the parameters for analysis and calculation of capabilities.

For each representative assortment or product defined it is required to establish its name, the main raw materials used in production, product dimensions, price and weight.

4. Definition of each plant infrastructure

As part of the procedure for the calculation, assessment and analysis of production capacities in enterprises (Gomez et al. 2007) it is required to define the

operation it will define the operating time per representative product unit and the type of equipment used. For each type of equipment will be defined the indicator that best reflects its technical ability (for example: power, speed), and the criteria for setting the operating times depending on the technical capacity indicator is defined for each one.

9. Calculating the capacity of each plant

Once you have the information on the preceding steps of the procedure is able to calculate the production capacity of each plant. From the data resulting from the above steps is necessary to implement the program Capacity 11a.xls to calculate the capacity of each plant, considering the structure and magnitude of demand.

The result of this step is the number of physical units of each type of product that can be made in each sector of plants.

10. Balance of sector capabilities

The balance of sector capabilities is to compare the actual demand with the sector capabilities to determine if these demands can be met, the balance must be conducted not only at the overall sector, but must be done at local level.

In Cuba one of the productions which currently have an administrative, geographic and technological dispersion is the aluminum carpentry for construction. As part of updating the Cuban economic model is necessary to reorganize the production of the aluminum and chart a national policy in this regard to ensure the demands of customers in an efficient, effective and competitive way. The basis of the reorganization of the productive sector took up the study of productive capacities developed under the procedure proposed in this article.

To calculate the capacity of the productive sector of the aluminum a list of all workshops dedicated to this production and their infrastructure was obtained. After analyzing all of them were fixed the efficiency conditions under which the sector must be reorganized, and the pattern of production stability to be worked.

With a view to standardize the results and ease of interpretation was defined a technology type and a group of representative products in terms of the basic raw material used in their manufacture, in this way was possible the calculation of the capacity in each plant to consolidate in a general result and geographical areas that allows the balance between demands and capacities in each geographic region.

As a result of the study in the area of the aluminum carpentry, after having made the calculation of the capabilities and the appropriate balance, it has been possible to conclude that the existing capacities exceed 40% over the demands of this type of production, which shows an oversized capacity.

Regarding the relationship between the stability of the plants and the use of their capacities both real and achievable (Figure 2) a conclusion was that, although the stability achieved is low (reflecting the organizational and technological level that perform the various plants), the utilization levels obtained are well below those achievable with these levels of stability. The underutilization of capacity is determined basically by a production plan and material supply not in line with the available capacity. This is also corroborated by determining the correlation between stability and the actual level of capacity utilization which shows a correlation coefficient of 0.167, which indicates that they do not correlate.

The results of the capacity study of the aluminum carpentry has identified the level of excess capacity at the country level, and perform the regional balance, allowing to rationally link the different territories that have skills deficits with those who have an excess.

The methodology proposed here is applicable in business practice and useful to determine the extent of the productive capacity of an economic sector and their utilization levels.

» V. CONCLUSIONS

The algorithm developed for the production and service capacities calculation has been used in food production and distribution, retail, medical equipment support services and carpentry of aluminum production. It constitutes a second generalization of the algorithm outlined previously by the authors and it facilitates to extend its application to the diversity of processes (production, transport, storage, service, agriculture and others) that are integrated through of the supply chain management. The calculation of all process capacities are based on final demand in consumer and is a method of balancing capabilities in a network of processes of different nature and with a variety of products.

The reached model allows balancing the capacities of the integral processes of the supply chain in such way that it makes sure to satisfy the demands of the customers and to

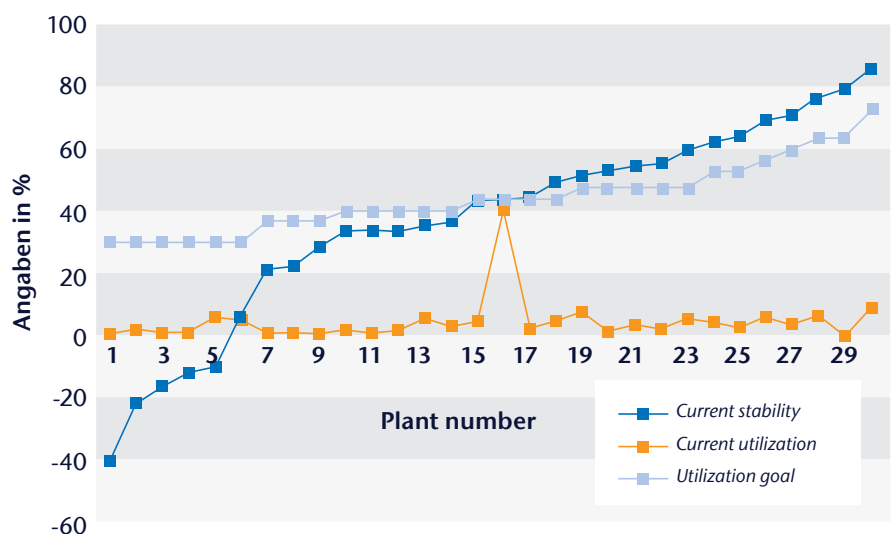


Fig. 2) Capacity utilization vs. stability

reduce the costs of capacities under utilization, which constitutes a factor that generates increment of the logistical costs.

Starting from the presented examples is demonstrated that the applying of the mathematical model proposed to the capacities analysis in supply chains can be used on varied nature processes. The form is also manifested in the improvement that can be reached in the capacities balance using the file *Capacidad11a.xls* like implementation of the system of equations outlined by the generalization.

The two case studies showed that the capacity can be calculated in different sectors using a comparable procedure and calculation methods and can help to analyze the real situation of a process to define if it is possible to achieve the customers demand and demonstrate that it is necessary the use of mathematical and process theory and practice to make conclusions not based on empirical analysis. One key point is a reliable definition of the processes, the demand and the relevant data.

Ulterior researches should influence the integration of this algorithm with approaches and models of optimization and simulation with orientation to the customer and the supply chain.

REFERENCES

- J. A. Acevedo Suárez, M. Hernández Torres, et al. (1987): Perfeccionamiento de los métodos de cálculo de las capacidades de producción. *Revista Ingeniería Industrial*, 1987, No.(2): 111-117.
- J. A. Acevedo Suárez (2008): Modelos y estrategias de desarrollo de la Logística y las Redes de Valor en el entorno de Cuba y Latinoamérica.: Facultad de Ingeniería Industrial. Tesis para optar por el grado de Doctor en Ciencias, La Habana, Cuba, CUJAE.
- J. A. Acevedo Suárez, M. Hernández Torres (2001): et al. Gestión de las capacidades en los sistemas logísticos. Bogotá (Colombia), Corporación John F. Kennedy.
- J. J. Anaya Tejero (2007): Logística integral: la gestión operativa de la empresa. 3ra. edición, Madrid.
- D. Brinkmann, J. Lang, et al. (2011): Towards a chain coordination model for quality management strategies to strengthen the competitiveness of European pork producers. In: *Journal on Chain and Network Science*. Volume 11, No. 2, 2011, 137-153
- J. Briz, et al. (2010): La Cadena de valor agroalimentaria. Análisis internacional de casos. Ed. Agrícola, Madrid.
- S. Chopra, P. Meindl (2010): Supply Chain Management. Strategy, Planning, and Operation. 4ta. New Jersey, EUA, Pearson Educatio.
- M. Espinoza Mesa, M. Mesa Olivera (2010): Aplicación del Modelo de Capacidad y del Modelo de Flujo en la Cadena de suministro de aceite comestible en Cuba.: Ingeniería Industrial. Tesis de Diploma, La Habana (Cuba), CUJAE.
- A. Kunkel (2003): Erprobtes Modell erleichtert die SCM-Einführung In: *Beschaffung Aktuell*, 2003, No.(2): 38-39.
- Ana M. García Pérez (2010): Inter-firm resources and the role of partners as determinants in the configuration and performance of interorganisational relations. In: *Journal on Chain Network Science*. Volume 10, No. 3, 2010.
- H.O. Günther, H. Tempelmaier (2005): *Produktion und Logistik*. Ed. Springer, 162-172.
- R. Koether (2008): *Taschenbuch der Logistik*. Ed. Hanser, Leipzig.
- E. Pérez Gorostegui (2010): *Curso de introducción a la economía de la empresa*. Ed. Ramón, Aricas, Madrid.
- I. Soret Los Santos (2010): *Logística y operaciones en la empresa*. Ed. ESIC, Madrid, 75-79.
- H. Winkler (2005) SCM- Implementierung auf Basis einer Virtuellen Supply Chain Organisation. In: *Supply Chain Management*, 2005, No.(11).

NACHWORT

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Prof. Dr.-Ing. Herbert Sonntag
Leiter Verkehrslogistik TH Wildau [FH]

AUTOREN

Igor Lopes Martínez
ilopes@ind.cujae.edu.cu

Yinef Pardillo Báez
yinef@ind.cujae.edu.cu

Ana Julia Acevedo Urquiaga
anajulia@economia.cujae.edu.cu

Martha I. Gómez Acosta
marthagom@tesla.cujae.edu.cu

José A. Acevedo Suárez
acevedo@tesla.cujae.edu.cu

ANSCHRIFT

Grupo Logespro
Facultad den Ingeniera Industrial
Technical University CUJAE, Havana, Cuba