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Design and construction of a quantitative model for the management of technology transfer at the Mexican elementary school system

Diseño y construcción de modelo cuantitativo para la gestión de transferencia de tecnología en la Escuela Primaria de México

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ABSTRACT

Nowadays, schools in Mexico have financial autonomy to invest in infrastructure, although they must adjust their spending to national education projects. This represents a challenge, since it is complex to predict the effectiveness that an ICT (Information and Communication Technology) project will have in certain areas of the country that do not even have the necessary infrastructure to start up. To address this problem, it is important to provide schools with a System for Technological Management (STM), that allows them to identify, select, acquire, adopt and assimilate technologies. In this paper, the implementation of a quantitative model applied to a STM is presented. The quantitative model employs parameters of schools, regarding basic infrastructure such as essential services, computer devices, and connectivity, among others. The results of the proposed system are presented, where from the 5 possible points for the correct transfer, only 3.07 are obtained, where the highest is close to 0.88 with the availability of electric energy and the lowest is with the internet connectivity and availability with a 0.36 and 0.39 respectively which can strongly condition the success of the program.

Keywords: Tecnological Management, quantitative model, infrastruture.

RESUMEN

Hoy en día, las escuelas en México cuentan con autonomía financiera para hacer inversión en infraestrutura, aunque deben ajustar sus gastos a los proyectos nacionales de educación. Esto representa un reto, ya que resulta complejo preveer la efectividad que tendrá un proyecto en TIC (Tecnologías de la Información y la Comunicación) en ciertas zonas del país que ni siquiera cuentan con la infraestructura necesaria para su puesta en marcha. Para abordar este problema, es importante dotar a las escuelas de un Sistema de Gestión Tecnológica (STM) que les permita identificar, seleccionar, adquirir, adoptar y asimilar tecnologías. En este trabajo se presenta la implementación de un modelo cuantitativo aplicado a un STM. El modelo cuantitativo emplea parámetros de escuelas con respecto a infraestructura básica como servicios esenciales, dispositivos informáticos, conectividad, entre otros. Se presentan los resultados del sistema propuesto, donde de los 5 posibles puntos para la transferencia correcta sólo se obtienen 3,07, el más alto es cercano a 0,88 con la disponibilidad de energía eléctrica, y el menor es con la conectividad y disponibilidad de Internet con A 0,36 y 0,39 respectivamente, lo que puede condicionar fuertemente el éxito de los programas.

Palabras clave: Gestión Tecnológica, Modelo Cuantitativo, Infraestructura.

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Introduction

Nowadays, the Mexican elementary school system is at a stage of transition from the old model where all the skills developed by the students were obtained from the interaction inside the classroom to a new model that involves the use of technology as a way to improve learning, especially in the domains of science, by making the learning process not totally dependent on what the student learns inside the classroom, but by making technology a tool to make knowledge available everywhere. As a result of this change in the educational model, schools now have financial autonomy, but this autonomy becomes a challenge in schools where computers or the internet have never been available (Román & Murillo, 2012).

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According to the National Institute of Statistics and Geography (INEGI) (INEGI, 2013), only 45,674 of the elementary schools in Mexico have at least one computer for education purposes. In addition, unequal spending affects marginalized areas, as 26,080 internet-service schools can be divided into 3 types, primary schools, indigenous primary schools and community elementary schools. From them, 67 % of primary schools have Internet, only 31 % of the indigenous schools and 1.6 % of the community ones; despite the fact that since 2004, the government have focused its efforts on the task of integrating Information Technology and Communication (ICT) resources in all the schools.

To address this problem, it is important to provide schools with a System for Technological Management (STM). This system allows them to identify, select, acquire, adopt and assimilate technologies. If the STM works adequately, schools will not only improve their infrastructure, but will also maximize the opportunities for children to acquire and develop skills in science areas (Gómez *et al.*, 2014). In order to do this, the STM works with a set of parameters, the parameters are applied to a quantitative model that analyzes the level of technological development per institution. It is expected that based on the results, schools develop policies and strategies with the purpose of fulfilling their needs (Fúquene, Castellanos, & Fonseca, 2007).

Specifically, in the education sector, proposals have been made to quantify the impact that technology has on the teaching-learning processes, such as those presented by Prieto Díaz & Quiñones (2011), Graells (2013),, Trahtemberg (2000), Cabrera (2006) and Álvarez (2009).

Another perspective that is important to address in the education sector is the technological appropriation, which can be defined as taking something that belongs to others and making it their own, which would imply relocating the responsibility of transferring the technology acquired by the individual to other contexts (Colas & Jiménez, 2008). Laffey (2004) analyzed the appropriation, domination and resistance of preschool teachers, Rodríguez and Steel (2003) established a permanent professional development model for the appropriation of ICT resources and Yi- Mei (2005) conducted a study on learning perceptions and technological appropriation of students in online learning environments.

In this paper, the implementation of a quantitative model applied to a STM is presented. The quantitative model employs parameters of schools, regarding basic infrastructure such as essential services, computer devices, connectivity, among others (Bogoya & Bogoya, 2013); the parameters previously mentioned were taken from INEGI (INEGI, 2013). The results obtained by the quantitative model are applied by the STM to determine school policies and strategies, as well as opportunity areas in which their money can or need to be invested (Torres, 2014).

Paper structure

The paper is organized as follows: Section II presents the mathematical support for the proposed quantitative model. Section III is the case study in which the model will be tested. Section IV are the results obtained from the application of the model to a STM, for the case of computers (laptops) that the Mexican government gave to elementary school students. Section V contains some final remarks and disscusion.

Design and construction of the model

Sabater (Sabater, 2010) considers 4 fundamental aspects to fully control the technological asset subject to the transfer and to successfully overcome the process, these aspects are classified as tangible, intangible, legal and adoption. The proposed model takes into account those aspects that have to do with the adoption process, which consider the necessary technological base in the institution for the implementation and its use, and available infrastructure; this takes on a significant relevance as shown by Cervera Gómez **et al.** (2008), Yepes (2010), Martínez & Heredia (2010) and Bosco (2008).

Assuming that there is a population of N institutions of basic education in Mexico, and must be divided into α_i classes (made for educational purposes, adapted for educational purposes, light and precarious materials, mobile school, no construction, unspecified), it can be determined that the probability of selecting some will be given by $I_K = N / ^{x}_{\alpha i}$. Thereby, constructing the initial selection vector, which will indicate towards which type of institution the technology is directed through the variable y_i^k. The latter will be binary and will take the value of one if the type of institution is selected for the acquisition and transfer of that technology or with a zero if it is not. Therefore, the vector can be written in the form:

$$SI = \begin{bmatrix} y_i^k I_1 \\ y_i^k I_2 \\ y_i^k I_3 \\ y_i^k I_4 \\ y_i^k I_5 \\ y_i^k I_6 \end{bmatrix} \quad (1)$$

Here, SI described in equation (1) is the initial selection, I_1 is the probability that the institution selection is made for educational purposes, I_2 is the probability that it is adapted for educational purposes, I_3 is the probability that the institution has light and precarious materials, I_4 is the probability that the institution is a mobile school, I_5 is the probability that the selected institution is unconstructed and I_6 is the probability that the institution will be unspecified.

Once the initial situation of each type of institution described by the initial selection vector is considered, the diagnoses carried out by CEMABE (INEGI, 2013) should be taken into account. They establish the conditions in which the institutions' infrastructure is located in elementary schools, these conditions will be structured in a set of vectors to be able to identify the conditions for the achievement of technology transfer (Ramírez, 2006).

The first element to consider is the material of the floor in the institutions, reason why, it can be written like:

$$MP = [y_i^k MP_1, y_i^k MP_2, y_i^k MI \quad 2$$

Where MP (Eequation (2)) is the material of the floor and $MP_i = N / P_i$, which is given by the probability of N institutions of basic and special education in Mexico have the type of floor P_i, being P_1 of soil or removable materials, P_2 firm cement and P_3 of wood, mosaic or other coating. On the other hand, the variable y_i^k, which is binary, will take the value of one if the type of floor is required for correct acquisition and transfer of the Technology, and zero if it is not.

Applying the same principles to the rest of the variables, the following vectors can be formulated:

$$MR = [y_i^k MR_1, y_i^k MR_2, y_i^k MR_3, y_i^k MR_4, y_i^k MR_5, y_i^k MR_6] \quad 3$$

In which MR (Equation (3)) is the wall material and $B_i = N / R_i$, which is given by the probability of N institutions of elementary education in Mexico have the type of wall R_i, where R_1 is of waste material, R_2 of sheet of Asbestos, metal or cardboard, R_3 of clay, reed, bamboo or palm, R_4 wood, R_5 Adobe and R_6 of partition, brick, block, stone, quarry, cement or concrete. The variable y_i^k, which is binary, will take the value of one depending on whether the type of wall is required for the correct acquisition and transfer of technology and zero if it is not.

$$MT = [y_i^k MT_1, y_i^k MT_2, y_i^k MT_3, y_i^k MT_4, y_i^k MT_5, y_i^k MT_6] \quad 4$$

Here MT described in equation (4) is the material of the walls and $MT_i = N / T_i$,i, which is given by the probability of N institutions of elementary education in Mexico have a type of roof T_i, being T_1 of waste material, T_2 of asbestos sheet, metal or cardboard, T_3 of wood, shingles, palm or straw, T_4 terrado with truss, T_5 tile and T_6 concrete slab or beams with vault. The variable y_i^k, will take the value of one if the type of roof is necessary for the correct acquisition and transfer of technology and zero if it is not.

$$DA = [y_i^k DA_1, y_i^k DA_2, y_i^k DA_3, y_i^k DA_4, y_i^k DA_5] \quad 5$$

Where DA (equation 5) is the availability of water and $DA_i = N / A_i$, which is given by the probability of N institutions of elementary education in Mexico have a water availability A_i water, being A_1 availability through public network, A_2 availability by means of pipe, A_3 availability by means of well or noria of the building, A_4 availability of water by means of transport, A_5 other type of means to ensure the availability of water. The variable y_i^k, will take the value of one depending on whether the type of water availability is necessary for the correct acquisition and transfer of technology and zero if it is not.

$$DE = [y_i^k DE_1, y_i^k DE_2, y_i^k DE_3, y_i^k DE_4] \quad 6$$

DE Equation (6) is the electrical availability and $DE_i = N / E_i$ which is given by the probability of N institutions of elementary education in Mexico have an availability E_i of electrical energy, being E_1 availability of connection to the public service, E_2 availability by means of solar cells, E_3 availability by means of own light plant, E_4 other type of means to ensure the availability of electric energy. The variable y_i^k, will take the value of one depending on the type of availability of electrical energy is necessary for the correct acquisition and transfer of technology and zero if it is not.

$$SS = [y_i^k SS_1, y_i^k SS_2, y_i^k SS_3, y_i^k SS_4] \quad 7$$

Where SS Equation (7), describes the health services necessary for the acquisition and transfer of technology and $SS_i = N / S_i$, which is given by the probability that N institutions of elementary education in Mexico have a type of sanitary service S_i, where S_1 availability of cistern, S_2 availability of latrines, S_3 toilette availability, S_4 drainage availability. The variable y_i^k, will take the value of one depending on the type of health service is necessary for the correct acquisition and transfer of technology and zero if it is not.

$$CE = [y_i^k CE_1, y_i^k CE_2, y_i^k CE_3] \quad 8$$

Here, CE shown in Equation (8) describes the connectivity and computer equipment necessary for the acquisition and transfer of technology and $CE_i = N / E_i$, which is given by the probability that N institutions of elementary education in Mexico have a type of connectivity and computer equipment E_i, being E_1 telephone line availability, E_2 availability of computer equipment, E_3 internet availability. The variable y_i^k, will take the value of one depending if the type of connectivity and computer equipment is necessary for the correct acquisition and transfer of technology and zero if it is not.

$$\boldsymbol{DB} = [\boldsymbol{y_i^k DB_1}, \boldsymbol{y_i^k DB_2}] \quad 9$$

In Equation 9, DB describes the availability of basic equipment in all classrooms to teach and that are necessary for the acquisition and transfer of technology, and $DB_i = N / B_i$ which is given by the probability that N Institutions of elementary education in Mexico have a basic equipment B_i, being B_1 availability of blackboard, B_2 availability of desk or board. The variable y_i^k, will take the value of one depending on whether the type of basic equipment is necessary for the correct acquisition and transfer of the technology and zero if it is not.

$$\boldsymbol{AC} = [\boldsymbol{y_i^k AC_1}, \boldsymbol{y_i^k AC_2}] \quad 10$$

AC (Equation 10) describes the accessibility to the computer equipment and if this is necessary for the acquisition and transfer of technology and $AC_i = N / C_i$, which is given by the probability that N institutions of elementary education in Mexico have access to C_i computer equipment, C_1 being accessible to computer equipment for students, C_2 accessibility to computer equipment for teachers. The variable y_i^k, will take the value of one depending on what type of accessibility is necessary for the correct acquisition and transfer of technology and zero if it is not.

$$AZ = [y_i^k AZ_1, y_i^k AZ_2] \qquad 11$$

Here, AZ shown in equation (11) describes internet accessibility and if it is necessary for the acquisition and transfer of technology and $AZ_i = N / Z_i$, which is given by the probability that N institutions of elementary education in Mexico have Accessibility to the Internet Z_i, being Z_1 accessibility to computer equipment for students, Z_2 accessibility to computer equipment for teachers. The variable y_i^k, will take the value of one depending on what type of internet accessibility is necessary for the correct acquisition and transfer of technology and zero if it is not.

$$SG = [y_i^k SG_1, y_i^k SG_2, y_i^k SG_3, y_i^k SG_4, y_i^k SG_5] \qquad 12$$

In Equation (12), SG describes the elements of security and prevention necessary for the acquisition and transfer of technology, and $SG_i = N / G_i$, which is given by the probability that N institutions of elementary education in Mexico have services of Safety and prevention G_i, where G_1 is protection signals, G_2 evacuation routes, G_3 emergency exits, G_4 safety zones, G_5 medical service or nursing. The variable y_i^k, will take the value of one depending on whether the type of security or prevention element is necessary for the correct acquisition and transfer of technology and zero if it is not.

With the above, probability matrices can be generated as follows (Equation (13))

$$A_1 = SI \; x \; MP \qquad 13$$

Which can be written as

$$A_1 = \begin{bmatrix} y_i^k I_1 \\ y_i^k I_2 \\ y_i^k I_3 \\ y_i^k I_4 \\ y_i^k I_5 \\ y_i^k I_6 \end{bmatrix} x \, [y_i^k MP_1, y_i^k MP_2, y_i^k MP_3] \qquad 14$$

Let $SI \in M_{n\times 1}(K)$ and $MP \in M_{1\times m}(K)$ be defined as the product of a function $M_{n\times 1}(K) \times M_{1\times m}(K) \to M_{n\times m}(K)$ such that $(SI, MP) \to A_1$, as demostrated in Equation (14). Hence the matrix A_1 is written as equation (15):

$$A_1 = \begin{bmatrix} (y_i^k I_1)(y_i^k MP_1) & (y_i^k I_1)(y_i^k MP_2) & (y_i^k I_1)(y_i^k MP_3) \\ (y_i^k I_2)(y_i^k MP_1) & (y_i^k I_2)(y_i^k MP_2) & (y_i^k I_2)(y_i^k MP_3) \\ (y_i^k I_3)(y_i^k MP_1) & (y_i^k I_3)(y_i^k MP_2) & (y_i^k I_3)(y_i^k MP_3) \\ (y_i^k I_4)(y_i^k MP_1) & (y_i^k I_4)(y_i^k MP_2) & (y_i^k I_4)(y_i^k MP_3) \\ (y_i^k I_5)(y_i^k MP_1) & (y_i^k I_5)(y_i^k MP_2) & (y_i^k I_5)(y_i^k MP_3) \\ (y_i^k I_6)(y_i^k MP_1) & (y_i^k I_6)(y_i^k MP_2) & (y_i^k I_6)(y_i^k MP_3) \end{bmatrix} \qquad 15$$

In the same way, the matrices A_2, A_3, A_4, A_5, A_6, A_7, A_8, A_9, A_{10}, A_{11} and A_{12} will be obtained by means of the product of Equation (1) and Equations (2), (3) , (4), (5), (6), (7), (8), (9), (10), (11) and (12). As a result, it is possible to write the transference model of educational technology as:

$$MT = A_1 + A_2 + \dots + A_n \qquad 16$$

Therefore, the MT described in equation (16) will have a value of $0 \le MT \le n$, depending on the number of criteria selected for the success of the transfer and assimilation of technology within the institutions of basic and special education, indicating that a trend value to zero indicates a low probability of adaptation and a value close to the maximum of selected criteria indicates a greater probability of adaptation.

Case of Study Mi Compu.Mx

In order to evaluate the effectiveness of the proposed model, the Mi Compu.Mx program will be reviewed, which grants laptops to fifth and sixth grade students in public schools. On November 25th 2013, the Digital Strategy was presented within the Office of the Presidency of the Mexican Republic. This strategy intended to cover five basic strategies, taking the third strategy of the five basic, as a guide to carry out this research. The third basic strategy is called “Quality education” whose objective is “Integration and use of ICT in the educational process to insert Mexico in the Information and Knowledge Society” (Gobierno de la República, 2013). Through this program, a product was designed exclusively for Mexico, which presented the characteristics described in Table 1 (Secretaria de Educación Pública, 2013) and which would be the basis for the operation of the program.

Table 1. Basic requirements for operation of computer equipment in the program Mi compu MX

Element	Features
Processor	Microprocessor with a minimum processing speed of 1.1 Ghz.
HDD	350 GB
Ports	USB.
Connectivity	Cards and components for access to the wifi network and bluetooth
Multimedia	Speakers, video camera and audio
Battery	Three hours’ capacity of continuous work
Preload	75 GB with application and multimedia content produced by the SEP and other public institutions. Anti-Theft Software

Source: Authors

Application of the model to the case study

Once the conditions and characteristics of the equipment to be submitted to the technology acquisition and transfer model are described, the minimum infrastructure variables that will be required for its correct operation are selected, as described in Table 2. With the program evaluation, it can be determined that 5 critical points are necessary for the correct transfer of technology, among these aspects are the electrical power supply, connectivity and computer equipment and internet accessibility.

Table 2. Selection of basic requirements for transfer of the technology of the program mi compu MX

Criteria to consider for the adaptation and assimilation of technology	Assessment
Floor materials	
Ground or removable materials	0
Cement or concrete	0
Wood, mosaic or other coating	0
Wall Materials	
Waste material	0
Sheet of asbestos, metal or cardboard	0
Cover with mud, reed, bamboo or palm	0
Wood	0
Adobe	0
Brick, block, stone, quarry, cement or concrete	0
Roofing Materials	
Waste material	0
Sheet of asbestos, metal or cardboard	0
Wood, shale, palm or thatch	0
Wooden frames	0
Roof tile	0
Concrete slab or joists with vault	0
Water availability	
Tap water system	0
No running water	0
Well water	0
Hauling water	0
Other	0
Water tanker	0
Electrical energy supply	
Connection to essential services	1
Solar cells	0
Electric plant	0
Other	0
Sanitary facilities	
Simple pit latrine	0
Restroom	0
Drainage system	0
Connectivity and computer equipment	
Landline telephone	1
Computer equipment	0
Internet	1
Availability of basic equipment in all classrooms for teaching	
Blackboard	0
Teaching desk	0
Computer equipment access	
Accessibility Students	0
Accessibility Teachers	0
Internet accessibility	
Accessibility Students	1
Accessibility Teachers	1
Safety and prevention	
Signs of protection	0
Evacuation routes	0
Emergency exits	0
Safety zones	0
Nursing service	0

Source: Authors

Results

Table 3. School base type

School base type for transfer of technology	
Type of school	**Evaluation**
Made for educational purposes	1
Adapted for educational purposes	1
Lightweight and precarious materials	1
Mobile school	1
No construction	1

Source: Authors

Table 4. Model Results

Basic infrastructure conditions		Made for educational purposes	Adapted for educational purposes	Lightweight and precarious materials	Mobile school	No construction	Sub-Total	No.	Probability of the event	Maximum limiting factors per project	Total point obtained
Electrical energy supply											
Connection to essential services	1	62,686%	24,106%	1,256%	0,12%	0,101%	88,2%	**6,1**			
Solar cells	0	0,000%	0,000%	0,000%	0,00%	0,000%	0,00%	**6,2**			
Electric plant	0	0,000%	0,000%	0,000%	0,00%	0,000%	0,00%	**6,3**			
Other	0	0,000%	0,000%	0,000%	0,00%	0,000%	0,00%	**6,4**	88,270%	1,00	0,883
Connectivity and computer equipment											
Landline telephone	1	25,554%	9,827%	0,512%	0,05%	0,041%	35,98%	**10**	35,984%	1,00	0,360
Computer equipment	1	27,812%	10,695%	0,557%	0,05%	0,045%	39,16%	**12**	39,163%	1,00	0,392
Internet Accessibility											
Accessibility for Students	1	38,966%	14,984%	0,781%	0,07%	0,063%	54,87%	**17**	54,870%	1,00	0,549
Accessibility for Teachers	1	62,692%	24,108%	1,256%	0,12%	0,101%	88,27%	**18**	88,279%	1,00	0,883
Totality										**5,00**	**3,07**

Source: Authors

When the number of elements necessary in the infrastructure of the elementary schools has been determined, the selection of the type of school in which the transfer of technology will be applied will be carried out. The program Mi compu.MX intended general, indigenous, migrant children, community courses and special educatio (Secretaria de Educación Pública, 2013), whereby the selection of the type of institution is made up as Table 3.

Running the model generates the results expressed in Table 4, which shows that of the 5 possible points that the MT can obtain, it only obtains a score of 3.07, achieving a higher score in the item of electrical energy supply and substantial deficiencies in the areas of connectivity and internet availability. This generates a probability of success for the acquisition and transfer of technology close to 60 percent.

Conclusion & discussion

In these days, there is no official evaluation of the program My Compu.MX, however different studies show interesting results that could help establish a panorama of the success of the program. In 2013, Díaz Frida (UNICEF & Arceo, 2013) showed that the lack of infrastructure in basic education and special education institutions is a strong constraint to the success of the program and the correct application of technology. Nevertheless, it mentions that in Oaxaca, through an agreement between government and internet service providers, a successful transfer could be made. In 2015 Rivera, Mercado and Ramírez, when applying an evaluation of the success of the program during its implementation, a series of administrative findings are what take more relevance, since they mention "That general institutions count with the technological devices, however, the lack of maintenance and failure of the internet networks or lack of access (school-house) tend to prevent an effective use of the devices". Díaz de León, **et al.**, in 2015, carried out a case study in the schools of Colima, Sonora and Tabasco. There, the feasibility for the implementation of the program MiCompu.Mx was a relevant complication in 32,3 % of the cases, and, from this. 51,2% pointed out infrastructure as key, especially the lack or insufficiency of Internet access, as the main cause for not achieving the development of the program. Finally, Aguilar **et al.** (2015) established three indicators for the analysis of the program, which are, organizational transformation, program implementation and impact on the family context, in a sample of 25 schools in which the program was promoted. Within the organizational context, the results indicate that the implementation of the program presented difficulties since it did not have the necessary infrastructure for the use of the equipment. It is necessary to asset that tecnnology is a differentiating tool that can lead to competitiveness and also can be a basic component either in organizational planning or development of political policies. Besides, technology management and technology per se have become and could be associated with organizations and the empirical know-how. Therefore, technology is now the pillar for getting competitive advantages (Fonseca, Castellanos, & Jimenez, 2012).

After analyzing the studies and applications implemented by different authors in the periods from 2013 to 2015, they are consistent with the results obtained in a quantitative way by the Transfer Model proposed in this article, starting from the premise that a maximum of 5 Points are possible, in order to achieve a correct technological transfer. Only 3,07 are obtained, where the availability of electric energy is the indicator with the highest score, obtaining about 0,88 points out of 1 (of the maximums to be obtained). Meanwhile, the lowest score is represented by Internet availability and connectivity with a score of 0,39 and 0,36, respectively, on the top 1 points. This allows us to conclude that with the results and coincidences found between the models presented by some authors and the one raised in this research, the success of the program can be strongly conditioned.

Finally, it is important to mention that this model aims to be a rapid aid for the formulation of educational policies in terms of the acquisition and transfer of educational technologies of various kinds with an emphasis on the specific needs of infrastructure, which can ensure the success in their application.

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