ON THE NEED FOR STRUCTURING OF THE INTEGRATED PUBLIC TRANSPORT SYSTEM -IPTS OF BOGOTÁ, COLOMBIA AS A VIABLE SYSTEM

SOBRE LA NECESIDAD DE ESTRUCTURAR EL SISTEMA INTEGRADO DE TRANSPORTE PÚBLICO -SITP DE BOGOTÁ, COLOMBIA COMO SISTEMA VIABLE

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ABSTRACT

Whilst there has been an increasing recognition that public transport systems are complex systems Lu and Shi (2007); (Pezzillo Iacono, Mangia, Canonico, & De Nito, 2010; Sienkiewicz & Hołyst, 2005) and therefore require complex systems approaches their analysis and design, there are not yet many examples in the literature to illustrate how this could be done and which would the learning be of taking such analytical approach. To contribute to this research path, this article analyses the trunk component1 of the Integrated Public Transport System of Bogotá (IPTS) as a business ecosystem, from the perspective of the Viable System Model (VSM). We first present the conceptual bases of the VSM and then present the methodological fundamentals to model the ITPS as a complex system under these chosen optics. Following a longitudinal analysis approach, we then model the complexity of the IPTS – and its environmental niche over the last 15 years since its inception. This preliminary analysis indicates that the development of the IPTS has not coped well with the variety of urban development, so the IPTS does not exhibit the requisite variety. A heuristic to continue this type of analysis is suggested that allows strategic systems' design and re-development, based on this model. Finally, we present our reflections on how this research path responds to existing questions in the literature on public transport systems and OR.

Keywords: Bogotá; Viable System Model (VSM); public transport; complexity; environment; management.

1 This trunk component is classified as a Bus Rapid Transit type (BRT). For more information about this form of mass public transport, consult the works of Vuchic (2002), Wright (2002), Levinson et al. (2003) e Darío Hidalgo (2005).

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RESUMEN

Si bien ha habido un reconocimiento creciente de que los sistemas de transporte público son sistemas complejos Lu y Shi (2007); (Pezzillo Iacono, Mangia, Canonico, & De Nito, 2010; Sienkiewicz & Hołyst, 2005) y por lo tanto requieren enfoques de sistemas complejos para su análisis y diseño, todavía no hay muchos ejemplos en la literatura para ilustrar cómo se podría hacer esto y cuáles serían el aprendizaje sea de tomar tal enfoque analítico. Para contribuir a esta línea de investigación, este artículo analiza el componente troncal del Sistema Integrado de Transporte Público de Bogotá (IPTS) como ecosistema empresarial, desde la perspectiva del Modelo de Sistema Viable (VSM). Primero presentamos las bases conceptuales del VSM y luego presentamos los fundamentos metodológicos para modelar el ITPS como un sistema complejo bajo estas ópticas elegidas. Siguiendo un enfoque de análisis longitudinal, luego modelamos la complejidad del IPTS y su nicho ambiental durante los últimos 15 años desde su creación. Este análisis preliminar indica que el desarrollo del IPTS no se ha adaptado bien a la variedad del desarrollo urbano, por lo que el IPTS no exhibe la variedad requerida. Se sugiere una heurística para continuar con este tipo de análisis que permita el diseño y re-desarrollo de sistemas estratégicos, basados en este modelo. Finalmente, presentamos nuestras reflexiones sobre cómo esta línea de investigación responde a las preguntas existentes en la literatura sobre los sistemas de transporte público y OR.

Palabras clave: Bogotá; Modelo de Sistema Viable (VSM); transporte público; complejidad; ambiente; administración.

INTRODUCTION

The Integrated Public Transport System of Bogotá (IPTS) was conceived as a solution to the traffic problems in the city (Acevedo et al., 2009; Urazán & Velandia, 2012). However, the complexity involved in timely responding to the increasing growth dynamics of the city (Echeverry, Ibáñez, & Moya, 2005; Peñalosa, 2005; Segovia & Fuchs, 2005) have resulted in obstacles to the evolution of the IPTS (Acevedo et al., 2009) in a way that could be not easy to guarantee the provision of this service while maintaining the same quality conditions with which it was conceived and that existed when it started its operation in the year 2001 (Cabrera-Moya, 2014).

Similar situations have been reported in other public transport systems around the world (see for example (Dirgahayani, 2013; Halden, 2002; Dario Hidalgo, Lleras, & Hernández, 2013; Pardo, 2009) and some researchers have suggested the need for designing and/or analysing them as complex systems (Guo & Wilson, 2011; Lu & Shi, 2007; Pezzillo Iacono et al., 2010; Sienkiewicz & Hołyst, 2005).

Some of the suggested alternatives to analyse these complex systems and their relationship with the evolutionary dynamics of cities, do it from the standpoint of the “business ecosystems” and their dynamic capabilities. For example Cabrera-Moya and Prieto (2013) and Cabrera-Moya (2016) used J. Moore (1993) concept of "business ecosystem". With the same idea J. F. Moore (2006) represents a variety of companies as complex systems coexisting in a network, by forming interdependent and symbiotic relationships. Inspired in his work, we explored the link between complex systems, dynamic innovation capacities and their contribution to generate sustainable competitive advantages. In this paper we continue this exploration, now under the perspective, of viable systems (Beer, 1984; Espinosa & Walker, 2017) and suggest new and innovative analytical routes to complement what has been done before.

The Viable System Model - VSM is as a theoretical framework to explain the way a neural network (heterarchical) type of organisation can deal with its environmental complexity, in a more effective way than traditional hierarchical organisations (Beer, 1979, 1981). It offers a robust theory to model organisations as 'business ecosystems' by exploring the analogies between the development of networked organisations and the systemic functioning of the human body.

In the last few decades, there have been a growing number of applications of the VSM, which have demonstrated its analytical power to map and self-transform a complex organisational system challenged by evolutionary dynamics that do not allow a timely response to the new operating conditions, due to the speed in which they arise (Espinosa & Walker, 2017). Nevertheless, in our review of the literature we did not find any application of the VSM to map the complexity of urban mass transport systems. There are some related works: a proposal to analyse the operation of government agencies related to transport infrastructure for railways and urban light railways (Hoverstadt & Bowling, 2002; Paradissopoulos, 1991); others to analyse the supply chains and their relationship with the operation of freight transport (Badillo, Tejeida, Morales, & Briones, 2015; Chroneer & Mirijamdotter, 2009; Puche, Ponte, Costas, Pino, & De la Fuente, 2016); and a few ones to design or simulate logistic distribution systems and the performance of supply chains from the perspective of the VSM, which include the transport of goods or people, but not necessarily as a mass transport system (Simatupang & Sridharan, 2002; Stich & Groten, 2015) , among others.

We consider that following the basic variety Laws and modelling principles supporting the VSM theory, we can contribute to identify useful strategies for redeveloping the IPTS as a more adaptive system, more capable of responding to the challenging combination of dynamism and multiplicity of scenarios it faces.

This paper discloses the necessary steps to model and assess a complex public transport system under this perspective: by providing a longitudinal mapping of the evolution of ITPS vs. the development of the neighbourhoods where it operates, we can demonstrate that the current system still does not exhibit requisite variety. We then compare our findings with complementary findings from the literature and discuss the value of this preliminary analysis for supporting strategy formulation for such type of complex systems design or redevelopment.

CONCEPTUAL BASES OF THE VIABLE SYSTEM MODEL (VSM)

Organisational cybernetics was developed by Beer (1959); (Beer, 1981, 1985). However, the origin of the concept ¨cybernetics¨ goes back to the Greek philosophers, who describe it as 'the science of governance'. More than a hundred years, when André-Marie Ampere used it to designate the field of study distinguished by processes of rules, patterns and organisation (Jutorán, 1994)).

Beer pioneered the Viable System Model, the funding theory of Organisational Cybernetics. He defines a viable system as the one 'capable of independent existence', which means, able to survive by adapting continuously to environmental changes. He developed the Viable System Model (VSM) as the theory that describes the necessary and sufficient (structural) conditions for any organisation to be viable. According to the VSM when these conditions are not met the organisational system becomes dysfunctional, and in the worst case, it may even collapse.

The VSM offers a structured meta-language to map structural complexity and detailed axioms, laws and principles to analyse the way operational teams and meta-systemic management roles interact between them and with their environmental niche. Following Espinosa et al (2008), we understand the 'niche' as those social, economic and environmental agents in the environment the organisation deals with directly when implementing its purpose (e.g. their business ecosystem). The VSM offer a set of conventions for modelling organisational, environmental and task's complexity as well as their interactions in a systemic way.

A viable system has three elements: operations (O), -the teams directly responsible the products or services which implement the organisational tasks; Metasystem (M) – which includes all managerial and technical roles and mechanisms to support operational tasks; and an environment within which it impacts and sustains itself (E) – which includes all the business ecosystem, including customers, suppliers, competitors etc. See Figure 1 below.

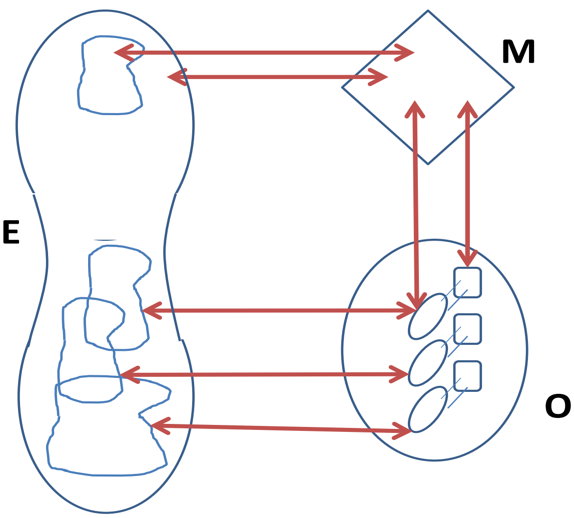
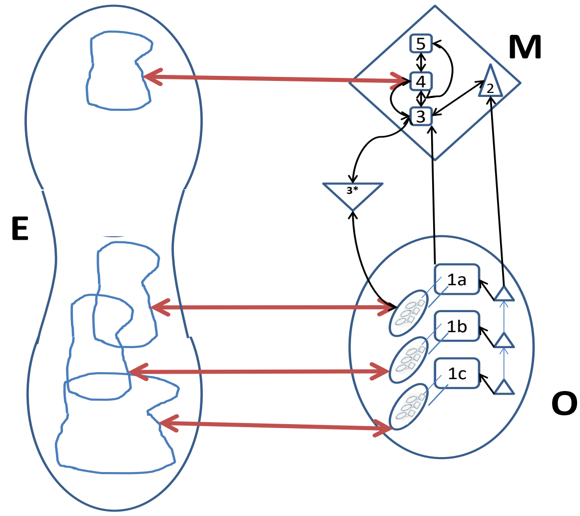


Figure 1. VSM basic diagram
Source: Authors based on Beer (1985)

The VSM also describes five typologies of organisational roles – which Beer calls Systems 1 to 5. Systems 1 – the operations are represented by an oval – together with their operational management – a little square connected to the operations, and the operational environment – the cloudy shape in the left-hand side. Systems 2 to 5 are represented by triangles and squares inside the metasystem (represented as a big diamond shape on top of the figure). See Figure 2.



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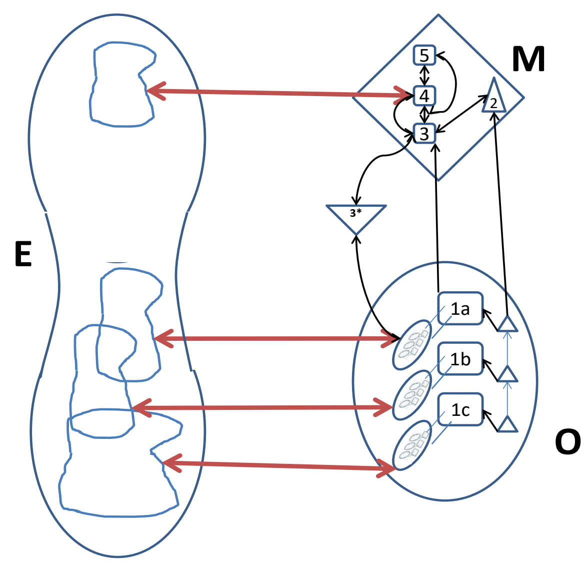

Figure 2. VSM relationship diagram MSV
Source: Espinosa and Walker (2017)

There follows a briefing on the definition of each system:

S1 or Operation, refers to the 'primary activities' - those directly responsible for producing the main products or services of the organisation. Each of them has their own operational management. Each of them is potentially a viable system on their own (able to self-manage and exist autonomously). Like in a neural network, each System 1 is an autonomous node, and the meta-system does not exercise authority over them, but provides meta-systemic services (e.g. resources management, accountability and normative support). S1 is directly in contact with its niche as proposed in Figure 3; as it is there where the organisation interacts with customers and suppliers; it is there where it exhibits more direct exchanges with the environment (as Beer would say more variety to manage).

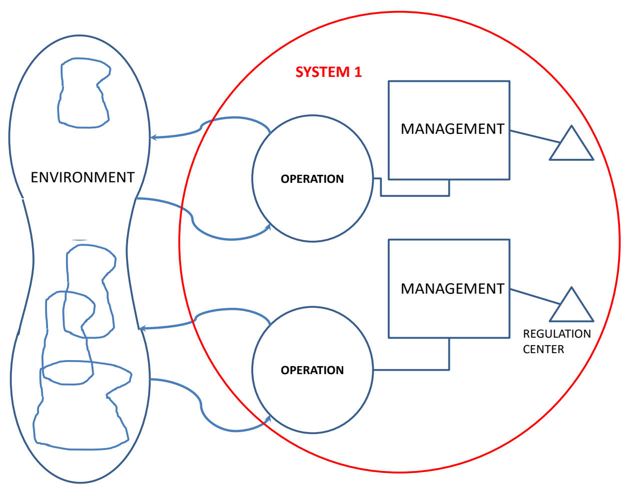

Figure 3. S1 components
Source: The authors based on Pérez Ríos (2008)

S2 prevents 'oscillations' or conflicts between the S1s, by providing shared languages, technologies, (e.g. information and communication systems), standards processes and procedures, and cohesive values. This harmonizing function supports the coordinated work of all operations as it`s proposed in Figure 4, by facilitating the sharing of resources and knowledge. Typical examples of Systems 2 are production programs, operating manuals and standards.

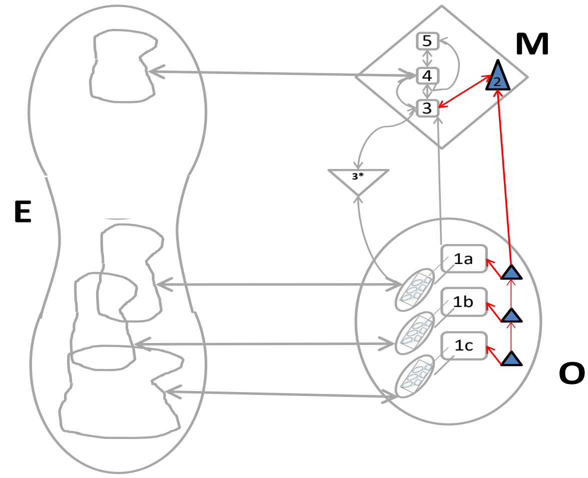

Figure 4. S2 system details
Source: The authors

S3 aims to guarantee the synergies and the cohesion between the S1. It promotes agreements about resource negotiations, accountability and Corporate and industrial Norms among operational and general management. System 3 aims to guarantee cohesion and synergies among the Systems 1. As each System 1 has their own operational manager, they interact with the general management of the organisation. The criteria for viability suggest that each S1 must have 'responsible autonomy' so must be able to take their own decisions on their day to day operations, for as long as they play within the constraints of organisational norms and available resources and are accountable for their own results. It also means that they should be able to self-regulate, and self-manage their information. A particular type of S3 is S3* whose elements and interactions can be seen in Figure 5 and which collects information directly from the source, in the event of unforeseen situations that require meta-systemic support. It does it by sporadically monitoring the individual and operational performance and the working infrastructure and climate by informal mechanisms, capable of capturing a wide range of information – e.g. ambiguous or messy information.

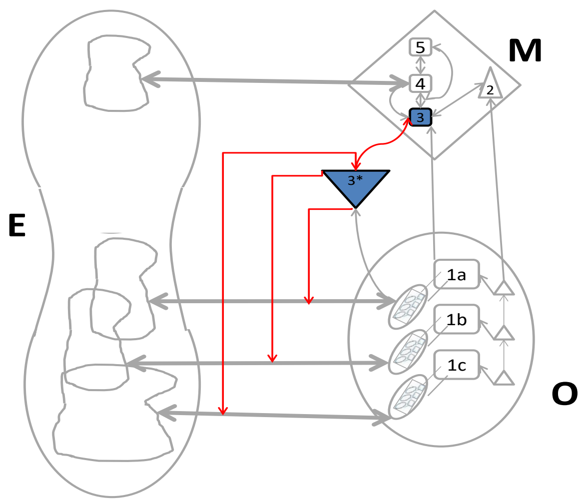

Figure 5. Participation of the S3 and S3* systems in the VSM
Source: The authors

S4 works as a learning engine that seeks to be alert to changes in the environment (scanning) that can positively or negatively impact organisational viability. For this, it develops organisational models, designs corporate strategy and ensures long-term financial viability by continuously learning about the evolution of the environment, which is why it is called a "learning engine". An important function of this system is to inform the organisation about the prospects for future development and the necessary adaptation; in that perspective, it is a function responsible for 'strategic search' ((Beal, 2000; Hambrick, 1982; Subramanian, Fernandes, & Harper, 1993)).

The S5 is in charge of designing and setting organisational identity and closure. It decides on organisational policies, and ethos, which represent the interests of ALL the stakeholders. S5 aims at achieving a balance between today and tomorrow's organisational needs, between internal situations and external conditions. It does it by guaranteeing an effective balance (homeostasis) between S3 and S4 roles in strategic and policy decision making.

A central aspect of VSM theory is the way it clarifies the idea of governance. A viable system is able to self-regulate and self-govern itself. To do so, there needs to be balance in the interactions between the Systems 1 and the environment; between the Systems 1 and System 3, between 4 and the environment. In addition, between Systems 3, 4 and 5. See Figure XX below. Each of the closed loops in the figure represents a homeostat – a mechanism to keep the organisation in balance – that means, to keep the essential variables within physiological limits.

To manage the environmental complexity, the organisation must have a rich model of the environment and a rich model of its own organisation:

A regulator needs to have at least as much variety as the system it aims to regulate (Conant & Ross Ashby, 1970).

S4 must have an updated and complete model of the organisation in order to match it with environmental changes and decide on adaptive strategies

We will analyse the information we have collected about the Transmilenio urban transport system – at the light of these criterion-. It will support a preliminary analysis of the regulatory capacity of the STPM system in Bogotá to reflect on their appropriateness of its current self-regulatory capabilities. This hopefully will inspire the design of heuristics for strategically analysing organisational development of such kind of complex transport systems.

Since Beer pioneered the Viable System Model, there have been increasing amount of methodological developments and practical applications, in fields as varied as organisational development, strategy, governance, information management, sustainability, and community OR – among others.- See Schwaninger (2006) for a summary of the development of Organisational Cybernetics; Schwaninger and Scheef (2016) for empirical confirmation of core VSM theoretical claims.

METHODOLOGY

Without any doubt, the IPTS is a complex system. According to Cilliers (2002) and Mitleton-Kelly (2003a) a complex system has a large number of variables and an even larger number of interaction among variables; its behaviours cannot be mapped with only traditional mathematical or computational methods. In order to understand and research complex systems, we need to use a multiplicity of methods, as we can't aspire to produce a complete mapping of a complex system or predict its behaviour, but we can only produce 'snapshots' of its behaviours and this way try to make sense of the underlying attractors or organizing forces. Mitleton-Kelly (2003b) of the London School of Economics highlight than the approaches, methods and tools in these cases must be able to track the organisational evolution by addressing both qualitative and quantitative aspects of it. She reports on the success of the use of this type of mixed methodologies in the collaborative work that the Complexity Group of the London School of Economics has been developing for three decades with different companies and describes the different qualitative and quantitative tools and methods that make up the integrated methodology (Mitleton-Kelly, Paraskevas, & Day, 2018).

On these reports, consulting firms such as EMK Complexity Group of the United Kingdom, Bain & Company and Grand Angle from France informs successful results when advancing business consultancies using a complexity approach. EMK highlight their work in association with a network of academics from different universities such as Cambridge, Durham, Glasgow, Hertfordshire, Lancaster, Lincoln, Oklahoma University, Sheffield or Warwick2. The work advanced in these companies covers a wide variety of disciplines using an integrated methodology that combines both qualitative and quantitative tools and methods to address complex practical problems. Bain & Company reports successful experiences across 15 kind of services in more than 40 industries working on over 500 projects to help companies manage complexity3. Grand Angle emphasizes its results in fields related to organisational barriers, business culture, management reform, culture formalization and crisis management among others[4].

Following a similar approach, we have chosen a combination of the following methodologies to analyse the complexity and adaptability of the STPM:

a. Qualitative (cybernetic) analysis to map the complexity of the IPTS system and to produce a snapshot of the IPTS environmental changes at a specific point on time. To progress in this direction, we will take inspiration from the first stages of Espinosa & Walker (2017) 'Self Transformation Methodology' – to do this analysis - see Appendix 1.
b. Statistical analysis of the dynamic evolution of the TM system over 10 years in different stages: 2005, 2010 and 2015. This analysis includes information about the interaction of the IPTS with the total of the geographical divisions in which the city is divided (called UPZ´s[5] - Spanish acronym for Zonal Planning Units). The details of this analysis will be explained later in the sections corresponding to the methodology.
c. This model combines the time series analysis (2005 - 2010 and 2015) and cross-sections of the interest groups defined in the section of databases to be consulted. This research design will allow us to analyse simultaneously the dynamic behaviour of the city growth and the heterogeneity between the organisations, during a decade. This proposed approach resembles Wooldridge (2001) cross sections

2 more information consult http://emk-complexity.org/projects/

3 For more information, consult https://www.bain.com/client-results/

4 For more information, consult http://www.grandangle-consulting.com/en/

5 These areas were created for the political and administrative control of the territory of the city by the DANE (Spanish acronym for Administrative Department of District Planning) through the "Decree 190 of 2004 POT". Its purpose is to "defining and specifying the planning of urban land, responding to the productive dynamics of the city and its insertion in the regional context, involving social actors in the definition of aspects of ordering and regulatory control. zonal scale "(Article 49).

combination model.

d. This approach allows us to analyse two aspects simultaneously: i) the specific individual effects that affect each organisation invariably over time and that conditioned the strategic decisions of these units, and ii) the temporary effects that affect them equally to all observation units at a given moment and which will generally correspond to macroeconomic or social policy phenomena.
e. Statistical analysis of changes in the environment (special urban blocks, streets, UPZs) using recent government surveys ("Bogotá cómo vamos").[6]

Figure 6 below presents our suggested Heuristic for Preliminary Analysis of viability of a Complex Urban Transport System. In the next sections we will test this heuristic method to observe and reflect on the past 10 years' growth of the IPTS; and on the basis of the learning from this exercise, we will suggest future research paths for further development and testing of this tool. We will also reflect on how this research contributes to similar queries in the transport and complex systems research communities.

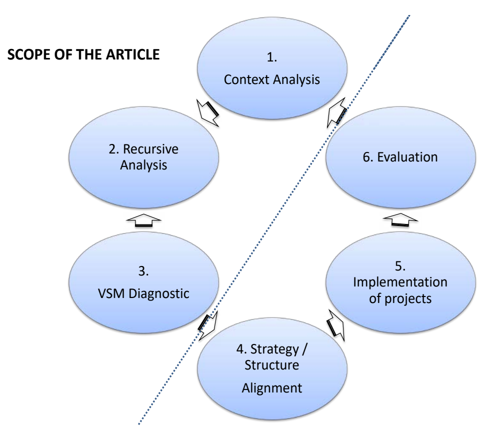

Figure 6. Heuristic Analysis Proposal
Source: The authors

6 Informe de la calidad de vida 2004-2007. http://www.bogotacomovamos.org/documentos/analisis-de-la-evolucion-de-la-calidad-de-vida-en/

Informe de la calidad de vida 2010

http://www.bogotacomovamos.org/documentos/evaluacion-de-los-cambios-en-la-calidad-de-vida/

Informe de la calidad de vida 2015

http://www.bogotacomovamos.org/documentos/informe-de-calidad-de-vida-2015/

HEURISTIC ANALYSIS PROPOSED FOR THE IPTS EVOLUTION

The complexity of both the number of companies involved in Bogota's IPTS, and its multiple interrelationships justifies its analysis from a complexity approach. We follow recent research explaining complex systems as business ecosystems (Battistella, Colucci, De Toni, & Nonino, 2013; Iyer, Lee, & Venkatraman, 2006; Iyer, Shankaranarayanan, & Wyner, 2006; Izquierdo & Izquierdo, 2007) who analyse the phenomenon and the characteristics of different typologies of clusters and business networks in developing countries. They also demonstrate that the uncertainty resulting from the absence of adequate models allow to minimize the effects of the heterogeneity of the information resulting from the different processes of the companies can lead to a market failure. We have also explained in more detail how to analyse Bogota's Public Transport System as an ecosystem and its relations with the citizenship (Cabrera-Moya, 2021; Cabrera-Moya & Prieto-Rodríguez, 2013).

Given the soundness and proven usefulness of the VSM (Anggraeni, Den Hartigh, & Zegveld, 2007; Preece, Shaw, & Hayashi, 2013; Wang, De Wilde, & Wang, 2009; Yolles, 2003; Zeng, 2003) and inspired in recent research explaining its use to analyse complex networks - see (Espinosa & Walker, 2017), we decided to suggest a heuristic approach by adapting the 'Self Transformation Methodology' to support the analysis of the IPTS of Bogotá as a viable system. Figure 7 shows the suggested heuristic approach, which include the following stages, each of them to be done iteratively in a longitudinal analysis:

1. Map the Business ecosystem
2. Define the Identity of the Network
   a. Elaborate a Rich Picture of the complex situation
   b. Agree on an identity statement (using the TASCOI tool)
   c. Analyse the Stakeholders
3. Unfolding of complexity and identification

of the System in Focus
4. Analyse viability of the system in focus
5. Repeat the analysis for every chosen time period
6. Produce recommendations for improved viability

The following section presents the analysis carried out by the authors for the IPTS in the last decade, following the stages of analysis suggested according to the proposal in figure 7.

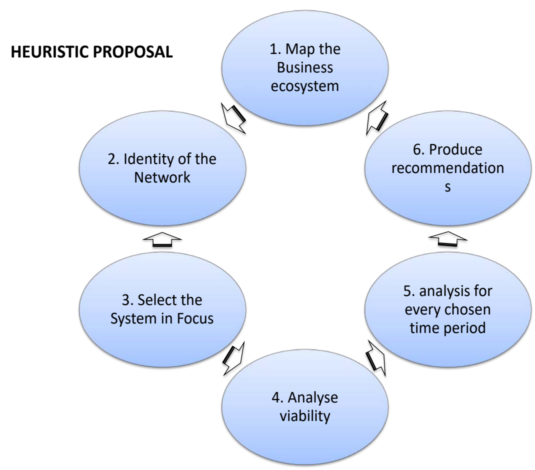

Figure 7. Heuristic for analysis of a business ecosystem as a viable system
Source: The authors

HEURISTIC ANALYSIS

Map the Business Ecosystem

Figure 8 represents the institutional components of the ITPS System. It provides more detailed information including new organisations or companies according to the requirements that were presented in different situations.

The authors suggest representing the IPTS as a viable system, i.e. as a neural network, or an ecosystem, to deepen into the analysis of levels of complexity of the interactions between IPTS stakeholders and its organisational actors and units.

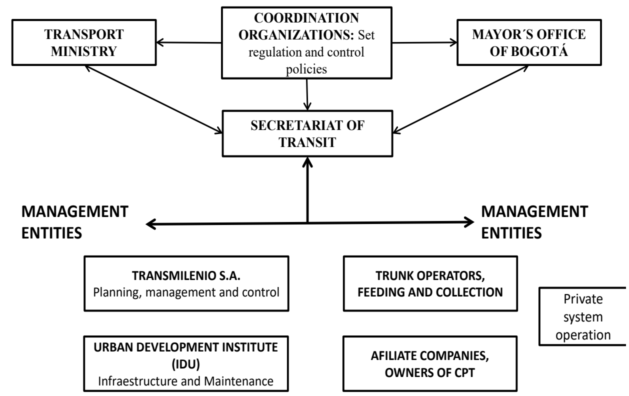

Figure 8. Institutional scheme of the IPTS
Source: The authors from the District Planning Secretary information

The ecosystem of the IPTS of Bogotá results from interaction between public and private companies from diverse sectors, that collaborate between them, to operate the urban transport system effectively. (J. Moore, 1993, 1996; Newman, 2003; Ritala & Almpanopoulou, 2017) describe typical features of an enterprise ecosystem. IPTS can also be described as a complex business system or as a viable system (Espinosa & Walker, 2017; Li, Fang, An, & Yan, 2014; Pérez Ríos, 2008; van Dijk & Rabellotti, 2005; Wang et al., 2009).

Table 1 summarises some of the main functions of every component inside the ITPS and their interconnections, according to the requirements that presented in different situations as shown in the Figure 9. The institutions in the system develop relationships of operation, collaboration, cooperation and co-development. Some of these relationships are symbiotic or interdependent which is common in complex systems, which can potentially co-evolve as viable systems.

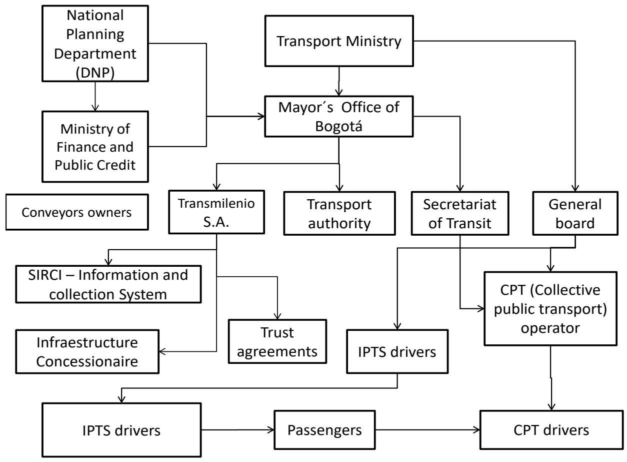

Figure 9. Detail of the institutional framework of the IPTS and the relationships between its components
Source: The authors

COMPONENTS	RELATIONSHIP
TRANSPORT MINISTRY – MAYOR´S OFFICE OF BOGOTÁ	Finance - Co-financing - Management of public and private money - Legislation and regulation
NATIONAL PLANNING DEPARTMENT (DNP) – MAYOR´S OFFICE OF BOGOTÁ	Finance - Co-financing - Management of public and private money - Legislation and regulation
MINISTRY OF FINANCE AND PUBLIC CREDIT – MAYOR´S OFFICE OF BOGOTÁ	Finance - Co-financing - Management of public and private money - Legislation and regulation
DIFFERENT KEY ACTORS OF THE SYSTEM – TRANSMILENIO S.A.	Legislation, financing, control, evaluation, direction in the implementation of infrastructure works and system operation
NATIONAL PLANNING DEPARTMENT (DNP) - MINISTRY OF FINANCE AND PUBLIC CREDIT	Pre-investment studies and prioritization of public expenditure
MULTILATERAL BANKING - MINISTRY OF FINANCE AND PUBLIC CREDIT	Credits with multilateral banks and commitment of future funds
TRANSMILENIO S.A. – DIFFERENT KEY ACTORS OF THE SYSTEM	Management Agency activities
TRANSMILENIO S.A. – CPT AND IPTS OPERATORS – DRIVERS	Operation in main routes, trunk lines, zonal and local lanes

Source: The authors

As an example of what was explained above, a VSM description of SITP at recurrence level 0 is proposed below. The operational performance is affected by the management of timetables, routes and schedules of the buses that integrate the IPTS fleet (including urban buses, trunk buses, feeders and complementary buses[7]. For more illustration of this analysis, see Figures 10 and 11.

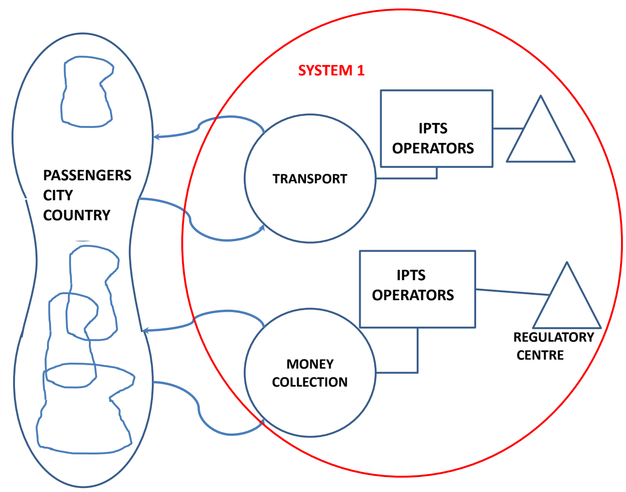

Figure 10. Diagrammatic representation of the IPTS as a VSM - S1.
Source: The authors

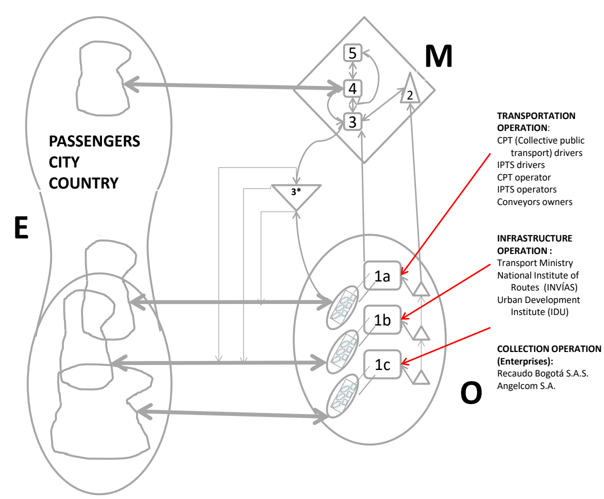

Figure 11. S1 proposal for IPTS as VSM
Source: The authors0

The Ministry of Transport, the Mayor's Office of Bogota and the Trust play an important role in developing tasks type S2. S2 harmonisation between public and private companies related to transport, telecommunications, collection,

7 For more information on characteristics of the System fleet, the reader is invited to visit the web-page http://www.IPTS.gov.co/Publicaciones/el_sistema/informacion_general

financial services, public works and the managing body of the system (Transmilenio S.A.). It allows the operational information to flow properly throughout the system, by avoiding delays or harmful interruptions during the provision of the service. Specific normativity, procedure manuals and operations manuals are issued by Transmilenio S.A in an attempt to unify the conditions of the entire fleet offering an effective process to the user. This is shown in Figure 12.

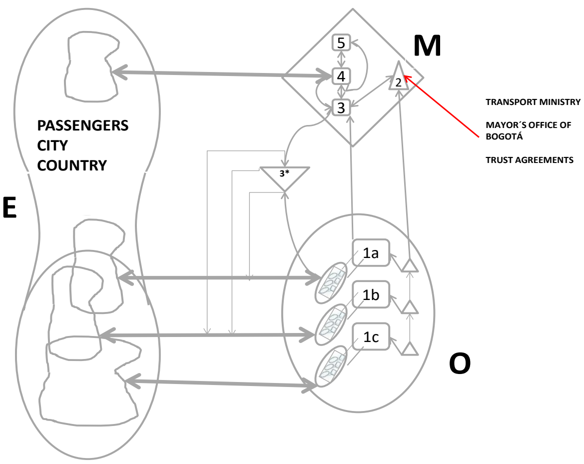

Figure 12. S2 proposal for IPTS as VSM
Source: The authors

S3 and the support system S3* of the IPTS attempt to coordinate the efforts of the entire operational component that is contained in S1, unifying the fleet and its components (refer to the different components of the fleet differentiated by colours, in the explanation of S1) to achieve the service unification. The operations engineering designed in the operations centre must be properly integrated so that the S3* can fulfil not only its intermediate work of support but also the management assurance process. The Management Information System of the process designated to cover the entire operation is the SIRCI - [integrated system for collection, control and information], works at this level. The Traffic Control Unit, Department of Transport and Infrastructure Concessionaire are advisory bodies and where acts as the head of the central system. This interaction is shown in Figure 13.

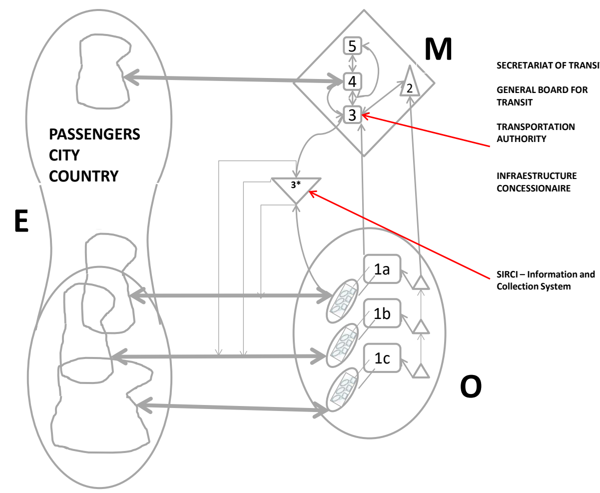

Figure 13. S3 proposal for IPTS as VSM
Source: The authors

The S4 shown in the Figure 14 corresponds to some requirements of local, departmental and national order that can affect the equivalent legislation in order to assure the sustainability of the system, through decrees and documents CONPES[8]. The DNP and the Ministry of Finance and Public Credit assure the required resources and budget to be able to respond to the changes in the environment, which allows getting a feedback whose purpose is to anticipate possible changes and define answers.

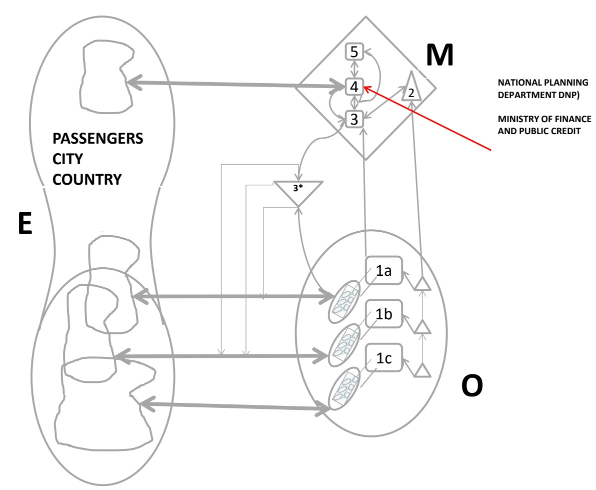

Figure 14. S4 proposal for IPTS as VSM
Source: The authors

Bogota Mayor's Agreement 04 of 2007 defines exactly the operation, objectives and strategic

8 Advisory body to the President on social and economic issues

plan of Transmilenio SA as the managing body of the IPTS of Bogota. In VSM terms, this agreement defines the S5 of the system -see Figure 15. There follows a summary of key elements of the 'ethos' of the system delimited throughout this section.

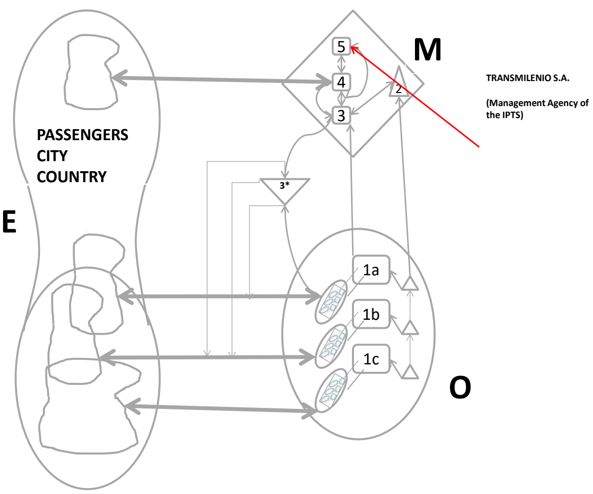

Figure 13. S5 proposal for IPTS as VSM
Source: The authors

Analysing the Network's Identity

Rich Picture

Many of the IPTS in the world have problems and Transmilenio is not an exception. One way to document them and which has been chosen in this study is by monitoring its performance based on reports from investigative units of local or national newspapers. According to (El Tiempo, 2017)[9] a variety of problems are associated with IPTS's operation and performance. A major problem is the low frequency of buses, which is insufficient to attend to the large number of users who access the System in different areas in peak hours. Experts say that having a larger number of buses is not the solution because although this would solve the problem of capacity, at the same time it would reduce mobility and increase travel times, a fact that is also highlighted as an inconvenience.

Other major weaknesses of IPTS are the inconvenience of traveling in fully crowded buses; lack of control of the routes; thefts inside the buses and in the stations; traffic jams on the roads that are sometimes insufficient to meet the growing population of Bogotá - that according to the latest statistics reaches 7 million inhabitants in 2015 (Publímetro, 2017; Revista DINERO, 2017), 7.4 million habitants in 2018 and it´s projected reach 7.9 million habitants in 2022 (DANE, 2022). See a rich picture of this situation at Figure 14.

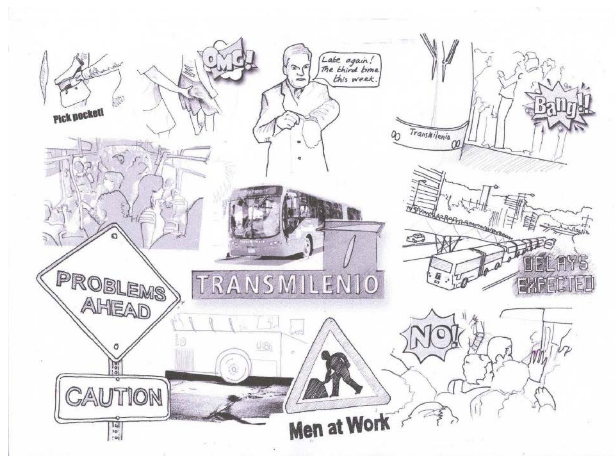

Figure 14. Rich picture for IPTS as VSM
Source: The authors

TASCOI (TRANSFORMATION, ACTORS, SUPPLIERS, CUSTOMERS, OWNERS, INTERVENERS)

T (to offer an effective and high-quality public transport service for the city of Bogotá).

A (IPTS workers, citizens, passengers, district authorities)

S (bus manufacturers, transport operators)

C (Citizens / users, operators/ workers)

O (District, Nation, Transport operators)

I (District Department of Mobility, Ministry of Transportation, City Hall, National Planning Directorate)

Identity Statement

9 EL TIEMPO newspaper, Bogotá-Colombia September 28, 2017

The IPTS aims to provide a good quality and effective public transport service to Bogota's citizens; -the district authorities (IDU, City Council, District Mobility Secretariat) are responsible for designing of the routes and for managing and improving the routes and schedules agreed for the systems operation. It also manages the BRT real time information systems about timetables and services (including the smart cards system that allows access to the system).It aims to satisfy the need for public transportation of the users of the Capital District and its area of influence, with standards of quality, efficiency and sustainability, through the planning, management, implementation and control of the operation of an integrated urban public passenger transport system, which operates under a public-private scheme that contributes to a greater competitiveness of the city and to the improvement of the quality of life of the inhabitants.

The IPTS has evolved through three phases with some differences in the operation of each of them. Phase I was extended from 2000 to 2001. Phase II began construction in 2002 and ended in 2006. Phase III included the new lines inaugurated between 2012 and 2015. The different conditions under which the adjudication processes were structured in each stage, defined different responsibilities for the operation. The maintenance of the roads and stations in Phase I are the responsibility of the District Authorities (IDU, City Council, District Mobility Secretariat), while in Phase II and Phase III this responsibility belongs to private operators.

Regarding the distribution of revenues, the official web page of the System points out that the distribution corresponds to 70.5% for articulated bus operators, 16.4% for feeder bus operators, 7.5% for ticket collection companies (sale and distribution of cards), 5.5% for Transmilenio SA and 0.039% for the fiduciary company that is in charge of distributing the income. Although Bogotá's total Public Transportation Service uses a wide variety of vehicles to provide the service throughout the city, two types of buses have been defined for the trunk operation. It is about the articulated buses that have a capacity to transport 160 people and the bi-articulated buses with a capacity of 250 passengers.

Recursive Analysis

The recursive analysis aims at discovering the Systems 1 of the whole network and to represent them as embedded systems within systems. Figure 14 presents the operational units of the IPTS as the different urban zones (UPZs); at each UPZ, the different stations, and within each station, the different routes it serves.

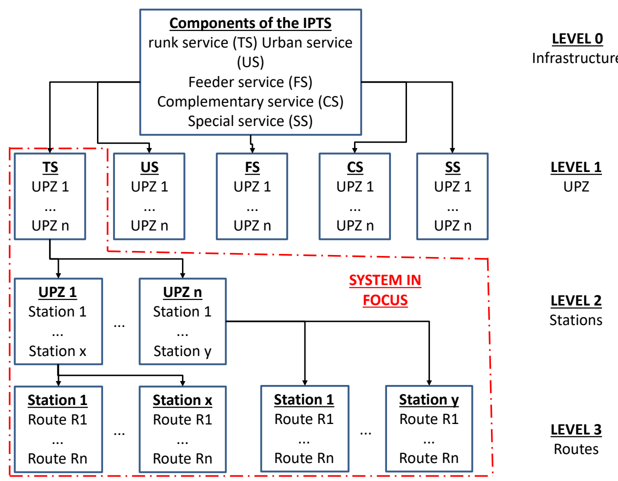

Figure 14. Recursive analysis for IPTS as VSM
Source: The authors

Operational Performance Analysis

Operational Performance Analysis

The Citizen Perception Surveys[10], are carried out to evaluate the level of perception of citizens about different public services in Bogotá. It offers statistics on the levels of use and the levels of acceptance and satisfaction of citizens about the core component of the Integrated Public Transport System.

10 This surveys could be consulted at http://www.bogotacomovamos.org/documentos/encuesta-de-percepcion-ciudadana-2016/, http://www.bogotacomovamos.org/documentos/encuesta-de-percepcion-ciudadana-2017/ and http://www.bogotacomovamos.org/documentos/encuesta-de-percepcion-ciudadana-2018/

This section analyses information corresponding to these variables in a 3-year time series between 2016 and 2018, simultaneously with the information on the evolution in the levels of use and in the geographical coverage levels of the System, in order to provide a comparative diagnosis between the operation and the quality of the service, in the period of time analysed.

Table 2 presents information related to the growth of the city's population in the years 2005, 2010 and 2015 and simultaneously the evolution of the geographical presence of the Transmilenio in Bogotá and the evolution of economic density in the same period of time. For the above, two geographical units of analysis called UPZ[11] and Urban Block[12].

Table 2. Service indicator of Transmilenio trunk service 2005-2015

Year	Population of Bogotá	Total UPZs in the city	UPZs served	Enterprises / urban block	Employees / urban block	Average distance from enterprises to BRT stations (meters)	total number of BRT stations	total number of BRT stations per served UPZ	Average of passengers (per day, per UPZ, per BRT station)
2005	6.778.691	112	33	9,89	42,59	1653,07	91	2,76	1.032.621 31.292 11.347
2010	7.347.079	112	44	10,10	36,37	1643,02	115	2,61	1.265.483 28.761 11.004
2015	8.193.260	112	52	12,59	96,58	1355,58	141	2,71	2.182.100 41.063 15.476

Source: The authors

The above information highlights the important growth that the presence of Transmilenio has had throughout the city and which can be seen in the increase in the number of UPZs served, in the decrease in the average distance of companies to the nearest station of buses as an indicator of the increase in the geographic presence of the system, in the increase of the total number of stations of the System in the city and in the sustained growth of the average number of users per day, of users per UPZ and of users per station. It also highlights the increase in economic and business dynamics that the city has experienced over the 10 years analysed, a fact that can be seen in the growing indicators of the average number of companies and the average number of workers per urban block.

Chart 1 and Chart 2 graphically present the information previously reviewed.

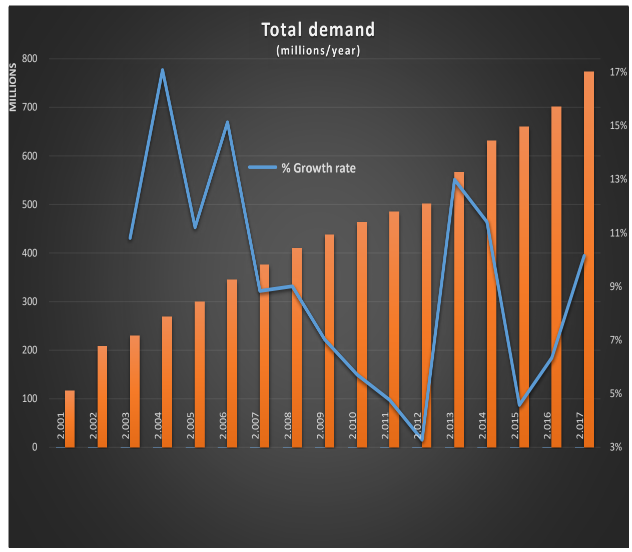

Chart 1. Total demand of passengers/year vs. Growth index

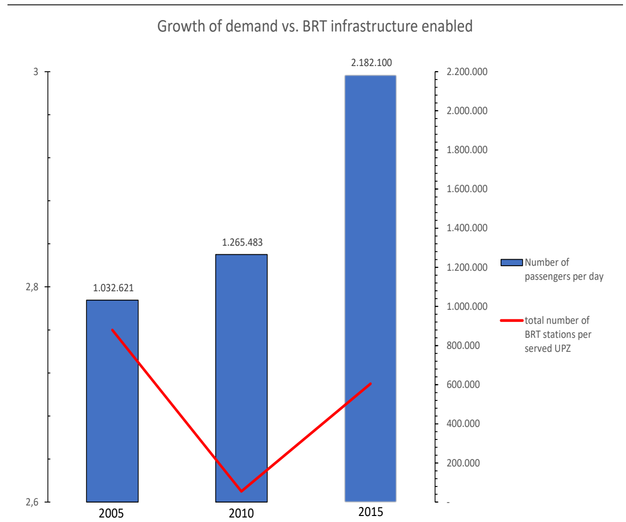

Chart 2. Increasing in the number of users and in the number of BRT stations per UPZ

11 The UPZ (acronym in Spanish for Zonal Planning Unit) are planning instruments that establish the urban regulation for a set of neighborhoods that have common characteristics in their urban development, as well as their predominant uses and activities. Its objective is to specify and complement the urban norm of the city from a more local scale and with the participation of citizens. For more information, please see www.sdp.gov.co

12 The urban blocks ("manzanas urbanas" in Spanish) are defined geographical units for the city and correspond to geographical spaces formed by buildings and contiguous structures delimited by streets, carreras (avenues perpendicular to the streets) or avenues, which usually have some level of access to endowment of essential public services such as aqueduct, sewerage, electric power, hospitals and schools. Fore more information, please see www.sdp.gov.co

Quality service indexes

This section further details the analysis of other previous broad diagnostic issues reported about IPTS. It first presents the percentage of IPTS use as the main means of transport reported by citizens. In 2016 this level reached 35%, while in 2017 these levels rose to levels of 37% and in 2018 they showed a small decrease to 35%. This variation is consistent with the growth levels of user demand shown in Chart 2 above.

Given that the main reference of the perception of citizens about the levels of quality of the System has to do with the degree of satisfaction as users, it is notorious that although levels of use have increased, levels of satisfaction have diminished. In 2016 this level was 18%, for 2017 it increased to 19% but by 2018 it presented a dramatic decrease to 13%. This figure can be analysed simultaneously with that reported by citizens in relation to their perception of the levels of improvement of the System.

In 2016, the percentage of users who considered that the service of Transmilenio had increased their levels of performance was 12%, whereas for 2017 and 2018 these levels registered values of 10% and 9% respectively. This means that the percentage of users who considered that service levels did not improve or worsened represented 88%, 90% and 91% respectively, which is very high, demonstrating the levels of dissatisfaction of citizens, an aspect on which the company it must ensure an immediate improvement.

As a consolidation of the information presented above, it can be highlighted that while the levels of use of the System and the levels of demand, as well as the levels of captive demand represented in the increase of companies and workers that could make use of Transmilenio, they also increased in the period analysed, the levels of perception and evaluation of the service and improvement of the quality thereof decreased.

The following is presented as one of the main arguments on the need to structure the Public Transport System of Bogotá as a Viable System in order to provide the organisation with the necessary elements to successfully face the changes related to the increase in demand of passengers of the System. Currently, it greatly exceeds the capability of the organisation to deal with the environmental variety and it is clear that Transmilenio needs to improve its coverage throughout the city, to guarantee a successful operation. In Chart 3 a comparative analysis of its historical evolution is presented.

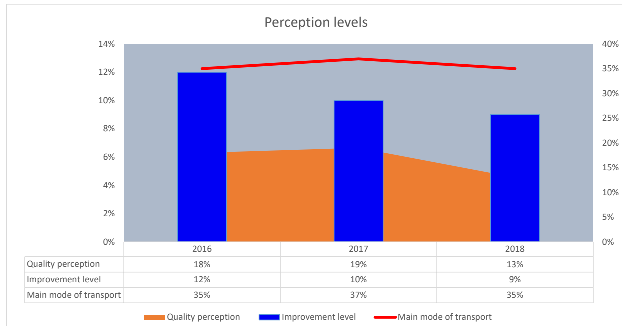

Chart 3. Comparison between the perception indexes on quality, levels of improvement and main mode of transport reported by the citizens

Variety Engineering Analysis

Based on the previous identification of main IPTS stakeholders, we will advance another step in the IPTS system's analysis, following the VSM principles - originally proposed by Beer (1994) and further detailed in Espinosa & Walker, 2017- see Figure 9.

To manage the environmental complexity the organisation must have a rich model of the environment and a rich model of its own organisation. Initially a regulator needs to have at least as much variety as the system it aims to regulate (Conant & Ross Ashby, 1970).

Later, S4 must have an updated and complete model of the organisation in order to match it with environmental changes and decide on adaptive strategies

We will analyse the information we have

collected about the Transmilenio urban transport system – at the light of these criterion-. It will support a preliminary analysis of the regulatory capacity of the STPM system in Bogota to reflect on their appropriateness of its current self-regulatory capabilities. That will inspire the design of heuristics for strategically analysing organisational development of such kind of complex transport systems

DISCUSSION AND CONCLUSIONS

The VSM and associated methodologies, offer a robust framework to analyse organisations experiencing difficulties due to the complexity of their interactions with their niches. When such an organisation is offering a public service, like transportation, which has a high incidence in the quality of life of the people, its full and effective provision becomes a key success factor for guaranteeing an equalitarian society. Understanding the GINI index in the recent evolution of the city allows to see that this is unfortunately- not the case in the city of Bogota. This coincides with multiples studies and complaints from the citizens of Bogota about the negative impact of Transmilenio's services in their quality of life. While this is all common parlance among the inhabitants, it is not easy to demonstrate in such a certain way, to convince the authorities on the need to address the IPTS's development from a different logic that is not only based in generating profits for the shareholders, but mostly in providing a more humane, satisfactory transport system, that truly contribute to improve the Gini index of the city, regarding this type of service.

We hope to have contributed to this purpose by providing a rigorous -and yet innovative- way of analysing the complexity of the system that demonstrates it's currently overloaded by variety and not copying with the developmental pressures of the city.

At the level of methodology we aimed at providing an innovative and practical tool for the analysis of complexity of public transport systems, which may be instrumental for supporting more robust strategic landscapes identification and discussion.

(. The IPTS evaluation presented here reveal the complexity of the relations between the different instances of this organisation and between the organisations that constitute the system. Although they all belong and are developed under the public transport industry, their nature is not homogeneous and evidences the need for a model that allows their simultaneous analysis.

This article is part of a research about the particularities of the IPTSs in Colombia, which proposes a strategic analysis framework based on the VSM approach to be applied to this type of transport projects.

As a methodological contribution for the strategic evaluation of transport companies, our proposal offers the necessary level of adaptability and flexibility in its components and structure, which offer the possibility to use our suggested framework for analysing different companies of land, sea, air or fluvial transport.

Based on the conceptual framework presented in Figures 1 and 2, the proposal for an appropriate structure for this type of organisation is developed, allowing the use of the essential processes of a VSM, which also allows to understand in detail the processes of the organisation, including the functions of each component, its operational structure and the heterarchy of responsibilities corresponding to each function. This proposal is shown in Figures 3, 4 and 5.

As emphasized in the Introduction, one of the main contributions intended in this article is to present a heuristic for strategic (re)design of a massive transport system, using the IPTS analysis as an example.

Due to the limitations manifested in the empirical literature where strategic assessment frameworks or methodologies based on a VSM model were presented, the need to submit a proposal of this type for the IPTS of Bogota was evidenced in order to allow the use of the flexibility and possibilities for self-regulation and self-organisation, which are made possible through this type of proposal, enabling its adaptation to the constant dynamism of the public transportation environment in complex cities such as the city of Bogota, delivering certain characteristics to the System which allow its structuring as a resilient organisation.

In this sense, a framework is proposed for the generation of strategic advantages through the contribution of the viable system model, which is applicable to organisations of the public transport sector, not only from Colombia but also from other countries that have implemented solutions of public transport systems with levels of complexity such as the IPTS of Bogota. This proposal is presented in the last section of this article as a contribution to future related investigations and as an approach to support future research topics.

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APPENDIX 1. THE SELF TRANSFORMATION METHODOLOGY (ADAPTED FROM ESPINOSA & WALKER, 2017)

There follows a briefing of suggested activities and tools at each stage:

Understanding Organisational Identity

The aim of this initial stage is to collectively agree and understand the organisational identity and its current way of interacting with its niche. In order to aid this learning aim, we always recommend to start by researching on key aspects of the organisation (e.g. products, market, mission, vision, structure, annual report, threats and opportunities).

This is done in preparation for a workshop, with as many representatives from the whole organisation, network or area under study, where we aim at producing a cartoon like representation of the organisation, and specifically of the main challenges and opportunities people see at the moment. This provides crucial information that the team can bring back into later modeling and analytical stages of the methodology. The analyst can facilitate this process by inviting all project team representatives to express in a humoristic way, using cartoons, the core problems/constraints they observe in the organisation. See below an example of a cartoon, produced in a systemic intervention in Hull Schools Business School in the 2000s.

By sharing others' perspectives, a more relaxed environment is normally created and a shared understanding of the nature of the required transformation emerges more naturally. As Checkland explained, dealing with complex problems through humour helps to change people's perception of the messy situation and leaves them in a more creative and collaborative mood to continue the systemic intervention (Checkland, 1981).

Afterwards, we facilitate an exercise with the participants for clarifying key organisational purpose and tasks, and the network of agents involved in implementing them. We suggest to use Checkland's (1981) CATWOE, and an agreement on a 'root definition' about the organisation or area under study; -for details on how to do this see Checkland (1981)-. Or alternatively, Espejo's TASCOI (Espejo, 2008), which is an adaptation of Checkland's CATWOE. Accoridng to Checkland, a root definition is a way of describing the core transformation that a human activity system produces: for example, if it is an organic farm, it may be using natural products (seeds, etc) to produce (and sell) organic food. If we are in a school, it may be using local talent to provide an educational service to local kids. The technique helps us to identify relevant agents involved in the transformation (i.e. suppliers, actors, customers, owners). While producing these definitions, the more supporting information we can provide to explain better the complexity of the transformation, the better we'll be prepared for the next diagnostic stages.

Recursive Analysis: Modeling Complexity Levels and deciding the system in focus

As explained in Chapter 2, a core aspect in using VSM for diagnostic purposes is to identify the

complexity levels that have 'emerged' while implementing the organisational tasks, or, in Beer's words, "to define the levels of recursion of the system in focus"(Beer, 1985).
In this stage the analyst will help the project's team to represent the levels of complexity that people recognizes when developing the organisational transformation identified. The core distinction that needs to be made here is to identify which are the primary and which are the support activities by which such transformation happens.

Primary activities are those directly responsible for developing the organisation's purpose, that is to say, producing the organisation's products or services. A primary activity normally has a clear boundary (a defined task); it has some resources allocated to implement its task (normally they are a budget centre in accounting terms and many times also share the same physical location); it has some managerial capacity (either a local manager or a local management team); it may potentially become an independent unit (is in itself a viable system). Complementarily, the purpose of any Support Activity is to provide support and/or resources to the Primary Activities, in order for them to be capable of producing their products/services. In this stage of the methodology we only model primary activities, and specifically their structural embeddings – or what we call its 'levels of recursive organisation'. Table A4.1 below details criteria to perform the recursive analysis.

In a diagram of 'Recursive Levels' we draw a circle for the organisation and inside it, we draw a little circle and name each one of the primary activities. From each little circle, we draw a connective line to another circle to 'zoom in' this primary activity. In this new circle –that will be at the next recursive level- we identify the primary activities embedded in the original one. We carry on this exercise of 'unfolding the complexity' of the organisation until there are no more primary activities.

Figure A1.2. Example of unfolding of complexity / a diary producing factory ()

As seen in the Figure above, each circle is a business unit: potentially a viable system itself, so we represent them as primary activities (in circles). The embedded sub organisations are linked to the mother unit by an arrow. We continue modeling all the structural embeddings until there are no more working team that fulfil the characteristics of a primary activity.

Once complete the recursive organisation diagram, we decide on the 'system in focus': we agree on the focus (topics) of our study and identify the organisational areas and levels responsible for the key business processes that are relevant to the focus of study. If may well be that the system in focus is the organisation as a whole. Once agreed the system in focus, we draw a boundary including the primary activities and the levels of organisation where we want to focus the analysis - see example in the Figure above-.

VSM Analyses

At this stage we will produce a VSM for each couple of nodes (parent and child) representing the (inverted) "tree" in the 'Recursive Analysis' diagram. Each VSM analysis will cover a family of nodes is the set of "branches" (uppermost node) and "leaves"' (nodes unfolding the tree's complexity).

In a VSM diagnosis stage, we begin by producing VSM analysis at each of the levels identified above. At each level, we begin by mapping the primary activities as the System 1, connect them with diagrammatic representations of Systems 2 to 5; draw the environment; and begin classifying the different roles regarding operations or management, by using the VSM distinctions (S1 to S5). Normally we do this through several workshops where progressively the participants learn the VSM systems and the laws and axioms of variety management. As a result of each workshop we focus more and more in identifying structural weaknesses, implementation gaps, and collective learning limitations. There follows more detail on the nature of the analysis required.

Aligning Strategy and Structure

One of current problems in organisations is that the process of defining organisational policies and strategies is not always aligned with the core structural issues. As a result, those expected to implement strategies are not always committed to them/ understand them / or have the skills/time/resources to implement them. No wonder why many strategic plans remain as good wishes and completely unlinked to practice. This has to do both with the way we formulate and implement organisational policies and strategies. The exercise we recommend in this stage is to reflect on current strategy and agree on which the critical success (or failure) areas from the organisation are required for implementing it, and then the critical success factors.

We'll assume here that there is a shared understanding and acceptance of current strategy, if this wasn't the case such shared agreement will need development before continuing the process. In order to define CSFs, the analyst should facilitate the necessary debates between the project's team, to reach agreements about those areas and topics which have a critical incidence in the successes or failures of their sub-organisation. Once identified the CSA, we can review our original definition of the 'system in focus' and make sure it include all these areas. The next stage- VSM design will concentrate in this (redefined) system in focus.

In order to agree on desirable changes to the recommended structure it's important to revisit the diagnostic results and suggest possible improvements to each of the weaknesses in the management of complexity found. This is normally done also through workshops where participants are invited to suggest alternative arrangements to overcome the current limitations.