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Sumario

Págs.

Editorial – Memoria Investigaciones en Ingeniería por tercer año consecutivo publica dos números por año.

Es un honor presentar a ustedes la edición Número 22 de la revista Memoria de Investigaciones en Ingeniería.

Esta revista viene siendo publicada de manera sostenida desde el año 2000 e integra diversos catálogos. Se encuentra en Latindex, cumpliendo las 38 características necesarias. Integra el Directory of Open Access Journals (DOAJ). Y está incluida en el catálogo Clarivate Web of Science (WoS), indexada en el Emerging Sources Citation Index (ESCI).

Desde el año 2020 Memoria edita dos números al año, uno en junio y otro en diciembre. Ello es muestra del sostenido crecimiento de la revista, de su aceptación por parte de los lectores, y la valoración que recibe de parte de los autores.

Los autores de los trabajos de este número son de la Universidad Cesar Vallejo de Perú, de la Universidad de Montevideo, Uruguay, de la Universidad de Cádiz de España y la Universidad de la República de Uruguay, y de la Universidad Tecnológica Nacional y de la Universidad Nacional del Litoral de Argentina. Estos trabajos han sido revisados por prestigiosos académicos de Iberoamérica.

Una vez más, tenemos el agrado de incluir un artículo realizado a partir de un trabajo premiado en el concurso de Tesis de Posgrado realizado por la Academia Nacional de Ingeniería de Uruguay.

A fin de 2021 se realizó en Montevideo el congreso IEEE URUCON 2021 (https://urucon2021.org/), organizado por la Sección Uruguay de IEEE. Memoria ofreció a autores de artículos presentados en este congreso la posibilidad de enviar versiones extendidas de sus artículos para ser sometidos al proceso de revisión de la revista. Se recibió un buen número de envíos. Uno de ellos es presentado en este número. Otros continúan en el proceso de revisión. Esta nueva modalidad de convocatoria se muestra beneficiosa para los autores, para los organizadores de congresos, para los lectores, y, en definitiva, para la revista.

Agradezco a los revisores actuantes en este número. Agradezco a la Lic. Valentina Morandi por su apoyo técnico permanente a la revista y especialmente al Ing. Fernando Hernández en su rol de Asistente Editorial.

Dr. Ing. Rafael Sotelo
Editor en Jefe
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Influencia de la adición del 0.2%, 0.3% y 0.4% de tereftalato de polietileno en las propiedades de resistencia y permeabilidad de pavimento de concreto

Influence of the improvement of 0.2%, 0.3% and 0.4% of polyethylene terephthalate on the strength and permeability properties of concrete pavement

Jazmin Alejandra Solórzano Ordinola [1], *Marco Antonio Cerna Vasquez Junior* [2]

Recibido: Febrero 2022 Aceptado: Mayo 2022

Resumen. - El objetivo de este trabajo fue evaluar el efecto del uso del PET reciclado en la elaboración de concreto para pavimentos, con la finalidad de promover su uso racional en lugar de desecharlo y disminuir la contaminación ambiental que representa el plástico PET. En esta investigación se comparó el concreto con agregado patrón diseñado para una resistencia de f'c=280 kg/cm2 con adiciones al 3%, 4% y 5% de PET en los ensayos de permeabilidad, compresión axial y flexión. Los resultados muestran que el PET en un 0.3% mejora la resistencia a la compresión, mientras que en un 0.4% de PET mejora la flexión y permeabilidad. Se concluye que si se busca la mayor resistencia se utilice menor dosificación de PET y si se busca mayor flexión y permeabilidad se utilice mayor porcentaje de PET. Este estudio demostró que el PET si influye significativamente en las propiedades físico-mecánicas del concreto permeable en pequeñas adiciones.

Palabras clave: Pet, Concreto, Compresión, Flexión, Permeabilidad.

Summary. - *The objective of the research is to determine the effect of the use of recycled PET on the permeability, compressive strength, and flexure of the permeable pavement f'c=280 kg/cm2. The methodology is applied type, experimental design, and quantitative approach. Permeable concrete is a type of porous pavement that seeks to solve the problems of traditional pavements, since traditional pavements, by not having an adequate gutter, tend to accumulate rainwater causing various accidents due to lack of inertia and decrease in pavement life. PET is a material that is found everywhere as waste, this material tends to resist tensile loads. The results show that 0.3% PET improves compressive strength, while 0.4% PET improves flexing and permeability. It is concluded that if the greatest resistance is sought, a lower dosage of PET is used and if greater flexing and permeability is sought, a higher percentage of PET is used. This study showed that PET does have a significant influence on the compressive strength, flexural strength, and permeability of pervious concrete.*

Keywords: *Pet, Concrete, Compression, Bending, Permeability.*

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1. Introducción. - A nivel mundial, el problema más conocido en la costa, países altos y zonas silvestres es el anegamiento de las carreteras provocado por las altas precipitaciones. Esto implica que la superficie de rodaje es de los puntos críticos conllevando a que se desintegre, al no tener una superficie permeable que permita dirigir el agua a través de conductos o vacíos [1].

A lo largo de los años, la necesidad del hombre de construir, lo ha obligado a añadir adiciones a la tierra y al concreto, lo que se ha visto reflejado en innovaciones en la ingeniería para dar solución a problemáticas sociales y técnicas [2].

Un dato muy importante es que el principal problema en el Perú y en el mundo es la contaminación ambiental proveniente del PET (tereftalato de polietileno). Esto se refleja en las 844.000 toneladas cada año u 8,9 kg/individuo/año, por lo cual, tratamos de darle un uso útil añadiéndolo al concreto [3].
La geografía peruana es tan diversa que en varios lugares se presentan inconvenientes de acceso, lo que ocasiona una sobreabundancia en zonas específicas, por lo que el estado peruano ha encontrado la manera de disminuir este exceso ampliando la cantidad de concesionarios [4]. Esta solución es importante pero no vital, ya que debe ir de la mano con una correcta configuración de mezclas según las necesidades requeridas según clima y geografía para pavimentos permeables [5].

En función a lo indicado, se tiene como objetivo general el determinar el efecto del uso del PET reciclado en la permeabilidad, resistencia a la compresión y flexión de un pavimento permeable.
Según la explicación de la problemática se plantea el siguiente problema general ¿Qué efecto tiene el uso de PET reciclado en la permeabilidad, resistencia a la compresión y flexión del pavimento permeable f'c=280 kg/cm2?

2. Marco Teórico. - El concreto permeable es un tipo especial de concreto con una alta porosidad, usado para aplicación en superficies de concreto que permita el paso a través de él de agua proveniente de precipitación y otras fuentes, reduciendo la escorrentía superficial de un sitio y recargando los niveles de agua subterránea [1].

En lo que respecta al diseño del pavimento de concreto permeable, se debe abordar desde un punto de vista estructural para garantizar la capacidad de absorber los esfuerzos y mantener su integridad durante la vida de diseño. Y, por otro lado, desde un punto de vista hidráulico para así validar la capacidad de gestionar el agua del evento máximo de lluvia para el cual ha sido diseñado [2].

El procedimiento constructivo de un sistema de pavimento de concreto permeable es diferente al empleado en la creación de pavimentos de concreto convencional; además, su criterio de aceptación no está basado en la resistencia a compresión, sino en la porosidad y permeabilidad, por lo tanto, tiene una perspectiva diferente [3].

La estructura de los pavimentos permeables consiste por lo general en tres capas: a) una superficie de rodamiento que permite la entrada del agua, que puede ser de diferentes materiales como asfalto, concreto (pavimentos porosos), arcilla, grava, pasto, b) una capa de base de material granular fino, la cual permite una instalación adecuada de la superficie de rodamiento y c) una capa compuesta por una matriz de material granular de gran tamaño o por módulos o geo-células plásticas donde el agua se almacena (sub-base) [4] .

En cuanto a cómo probar el concreto permeable, este debe ser diseñado para obtener una resistencia a la compresión entre 400 psi y 4000 psi (2.8 y 28 MPa), sin embargo, no se especifica o acepta en base a la resistencia. Un punto más importante es el contenido de vacíos. La aceptación se basa normalmente en la densidad (peso unitario) del pavimento en el sitio. Una tolerancia aceptable es de más o menos 80 kg/m3 de la densidad de diseño [1].

3. Metodología. - En el experimento se elaboraron 04 diseños de mezclas de concreto con diferentes porcentajes de PET reciclado (0%, 0.2%, 0.3%, 0.4%). Se moldearon un total de 48 probetas cilíndricas y 36 vigas, siendo las variables de evaluación que se midieron la resistencia a la compresión axial (ASTM C 39), resistencia a la flexión (ASTM C 78) y permeabilidad o Infiltración de Agua (ACI 522R-10). Para estos especímenes se consideraron tiempos de curado de 7, 14 y 28 días.

Para la fabricación del concreto se consideró cemento portland tipo I con una resistencia de diseño de 280kg/cm2. Se utilizaron gradación de agregados de 3/8" y 1/2" de la cantera Tres Tomas. En la presente tabla se presentan las principales propiedades de los agregados utilizados.

Tipo de agregado	**Agregado Grueso (3/8")**	**Agregado Grueso (1/2")**
Peso específico (seca)	2.58 gr/cm3	2.61 g/cm3
Peso específico (aparente)	2.69 gr/cm3	2.71 g/cm3
% Absorción	1.61%	1.53%
Peso unitario suelto	1486 kg/m3	1365 kg/m3
Peso unitario compactado	1695 kg/m3	1543 kg/m3
% Humedad	0.85%	0.16%
% Vacíos	12.10%	17.90%

Tabla I. Propiedades físicas de los agregados utilizados.

Las mezclas fueron dosificadas sin considerar agregado fino para cumplir con los parámetros de la norma ACI 522R para concretos permeables; en la tabla siguiente se presentan la dosificación utilizada para la fabricación del concreto.

Materiales	**Peso 1m3 (KG)**	**Proporciones en volumen**
Cemento	372.28	1
Agregado grueso	1573.24	4.23
Agua	151.51	17.30

Tabla II. Diseño de mezcla para agregado de 1/2''

Materiales	**Peso 1m3 (KG)**	**Proporciones en volumen**
Cemento	372.28	1
Agregado grueso	1705.06	4.58
Agua	143.05	16.33

Tabla III. Diseño de mezcla para agregado de 3/8''

4. Resultados y discusión. -

4.1. Resistencia a la compresión axial. - Se evaluaron 03 muestras de cada probeta cilíndrica de concreto con y sin PET reciclado para edades de curado de 7, 14, 28 días. Se presentó fractura de lados en la parte superior e inferior. Los resultados obtenidos cumplieron los requerimientos de la NTP 339.034 y se muestran a continuación:

Adición de PET Reciclado	**Resistencia a la compresión axial (Kg/cm2)**		
	07 días	14 días	28 días
0 %	193.52	251.68	281.68
0.2%	194.02	252.92	282.78
0.3%	194.63	253.28	283.64
0.4%	193.08	251.14	281.03

Tabla IV. Resistencia a la comprensión axial

En cuanto a la resistencia a compresión axial de probetas de concreto, los resultados son constantes para las adiciones 0.2%, 0.3% y 0.4% investigadas. En comparación con [6] se observa que, el concreto logró una mejoría al adicionar el PET en un 0.5%, ya que la resistencia a la compresión aumentó en un 12.33% a comparación de su diseño patrón, por ello coincidimos en que el PET si influye positivamente. Es importante resaltar que los resultados de [7], nos indican que para porcentajes mayores a 0.5% se presentan disminuciones considerables en esta propiedad del concreto.

4.2. Resistencia a la flexión. - Se evaluaron 03 vigas de concreto para cada condición de adición de PET reciclado para edades de curado de 7, 14, 28 días. A continuación, se presentan los resultados promedios:

Adición de PET Reciclado	**Resistencia a la flexión (Kg/cm2)**		
	07 días	14 días	28 días
0 %	22.99	30.77	36.50
0.2%	23.72	32.16	38.59
0.3%	24.70	34.34	40.83
0.4%	25.64	36.09	43.62

Tabla V. Resistencia a la flexión

Para el caso de la resistencia a la flexión, todas las adiciones estudiadas mejoraron esta propiedad. Pero, se obtuvo un incremento máximo del 19.51% al adicionarse 0.4% de PET reciclado. Estos resultados son similares con lo indicado por [8], que al adicionar PET al 0.50% se incrementa un valor de 14.04%. Con ello se demuestra que a mayor cantidad de PET se mejora la resistencia a la flexion del concreto dándole la calidad adecuada.

4.3. Permeabilidad. - Para el tiempo de 28 días se evaluaron 03 muestras cilindras para cada condición de adición de PET reciclado. Se indican los valores promedios:

Adición de PET Reciclado	Permeabilidad (cm/s)
	28 días
0 %	0.53
0.2%	0.56
0.3%	0.60
0.4%	0.63

Tabla VI. Permeabilidad del concreto

Para el caso de la permeabilidad, se evidencia que a mayor cantidad de adición PET, se incrementó la permeabilidad de manera proporcional. Cabe mencionar que los resultados cumplen lo dispuesto por el ACI 522R-10, en cuanto al coeficiente de permeabilidad del concreto permeable que debe estar dentro del rango de 0.1582 cm/s a 1.22 cm/s. Es importante indicar que todo lo mencionado se consolida con lo indicado por (6), que menciona que los valores más altos obtenidos se debieron a elaborar un diseño de mezclas que solo posee agregado grueso y por ende tiene más volumen de vacíos, lo cual drena el agua a través de su estructura.

4.4. Comparativo. - En función a las figuras I y II, si se busca mejorar la resistencia a la compresión, flexión y permeabilidad, el porcentaje más adecuado es 0.3% de PET. Esto se considera bajo las condiciones de diseño, tipo de agregados y proporción del PET.

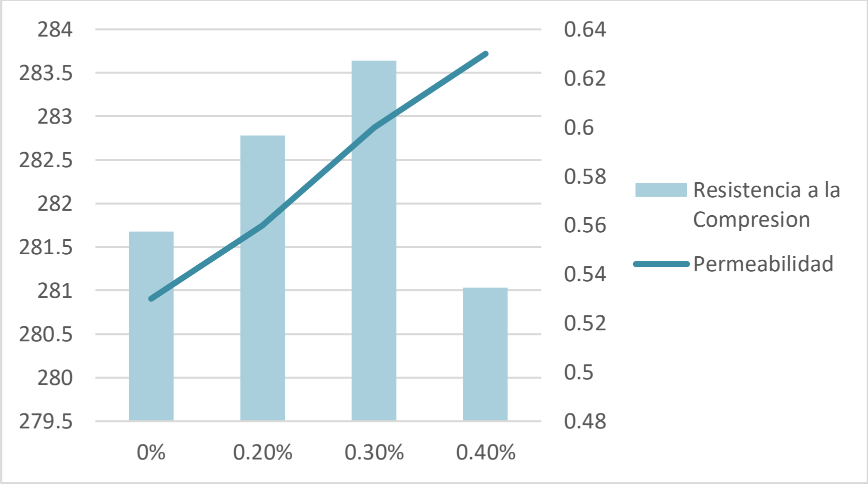

Figura I. Gráfica de Resistencia a la compresión Vs Permeabilidad.

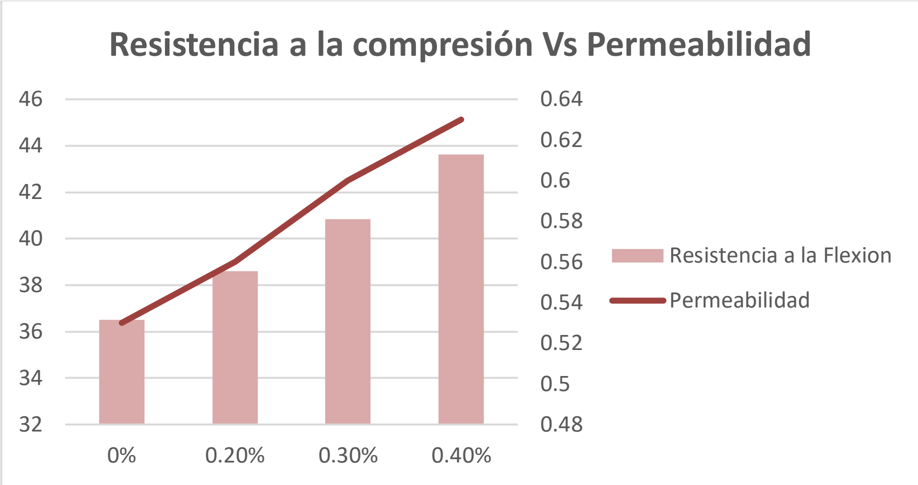

Figura II. Gráfica de Resistencia a la flexión Vs Permeabilidad.

5. Conclusiones y recomendaciones. - De acuerdo con los resultados de este estudio, en los concretos fabricados con PET reciclado se aprecia un comportamiento más favorable para un mayor porcentaje de PET. Tenemos para cada caso, en resistencia a la compresión para el 0.3% y resistencia a la flexión y permeabilidad al 0.4%.

Como conclusión, se puede establecer el uso del PET en pavimentos permeables tiene efectos importantes tanto estructural y económicamente.

Se recomienda utilizar el PET en diversos porcentajes y medidas ya que su aplicación en la construcción seria vital desde un punto de vista ambiental porque habría una disminución de la contaminación, mejorar la calidad de vida y plantear nuevas técnicas de construcción.

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Analysing the COVID-19 disruptive impact on Montevideo's Supply Chains

Analizando el impacto disruptivo del COVID-19 en las cadenas de suministro de Montevideo

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Summary. - Globally, COVID-19 reached unprecedented levels of contagion, affecting the social meetings, public spaces, and many everyday aspects. During the first days of the pandemic, supply chains were severely impacted by a great uncertainty in socio-economic terms, causing irrational variations and the inability to forecast demand. In this paper, the effect of the COVID-19 pandemic on the behaviour of different companies is analysed based on the variation in supply and demand of consumer-packaged goods. The pandemic outbreak disruption, the bullwhip effect caused by demand fluctuations, and the resilience of different companies were studied. A multiple case study methodology is used to analyse the decision-making process of fourteen different companies, from diverse sectors in Uruguay, affronting the pandemic. The paper's main findings include the identification of disruption and operation risks along with coordination in supply chain management during the first four months of the pandemic. Moreover, due to the necessity of sanitation and comestibles, and the fear of stockout, consumers' demand was uncertain, and the bullwhip effect was observed in critical channels of some products. Finally, the resiliency and robustness of the affected companies were studied and good practices for a resilient and robust response to the pandemic were identified and analysed.

Keywords: COVID-19, Logistics Management, Supply chain resilience, Bullwhip effect.

Resumen. - *Mundialmente, el COVID-19 generó niveles de contagio sin precedentes, afectando reuniones sociales, espacios públicos, y muchos aspectos de la vida diaria. Durante los primeros días de pandemia, cadenas de suministros fueron afectadas debido a una gran incertidumbre de factores socioeconómicos, causando una alta volatilidad en la demanda resultándola impredecible. Este artículo analiza el efecto que tuvo la pandemia en el comportamiento de diferentes empresas considerando las variaciones en la oferta y demanda de bienes de consumo envasados. Las perturbaciones generadas por la pandemia, el efecto látigo causado por fluctuaciones en la demanda, y la resiliencia de diferentes empresas son estudiadas. Se utilizan*

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múltiples estudios de caso para analizar el proceso de toma de decisiones de catorce empresas uruguayas, de diversos sectores, enfrentándose a la pandemia. Entre las observaciones realizadas se destacan la identificación de riesgos operacionales y disrupciones, y una alta coordinación en la administración de cadenas de suministro durante los primeros meses de pandemia. Asimismo, necesidades sanitarias y alimenticias, y el miedo al agote de stock, causaron demandas inciertas, ocasionando un efecto látigo en ciertos canales de productos. Finalmente, la resiliencia y solidez de las empresas es estudiada, y se identifican y analizan buenas prácticas para afrontar la pandemia.

Palabras clave: *COVID-19, gestión logística, resiliencia de las cadenas de suministros, efecto látigo.*

1. Introduction. - The COVID-19 outbreak represents one of the major disruptions encountered during the last decades and has drastically impacted most aspects of human activities [1]. It has had a profound impact on supply chains [2], and its unexpected nature has generated new trends in public behaviour, which made decision-making processes challenging for supply chain managers. Moreover, the impact and the duration of the pandemic were completely unpredictable [3].

Disruptive events such as the Coronavirus pandemic can be classified using different criteria [4, 5]. In terms of the disruption's lead time, this crisis was rapid (little or moderate advance notifications, present warning signs), severe considering the impact of loss (causing a high level of economic loss and/or many deaths), and international.

Every disruption has a time component to its effects, which is key for understanding its synergy and predicting its consequences [4, 6]. Generally, in the very first stage, the preparation stage, organizations can predict the event and plan operations to reduce its impact. This is followed by the first response period, where the aim is to control the situation, focusing on protecting lives and preventing further damage. After this, companies start recovery preparations, notifying the rest of the supply chain's links and redirecting resources. Finally, when companies make up for lost production, the recovery phase takes place, but generally, a long-term effect will persist causing a possible improvement in performance or a negative impact as customer relationships and trust may be damaged.

Pandemics and epidemics are a particular kind of disruption, as they are characterized by the three following components of threat: (1) the presence of long-term and unexpected scaling disruption, (2) disruption propagation in the supply chain and epidemic outbreak propagation in the population, and (3) disruptions in the development of logistics, demand, and supply [7]. In contrast to most disruption threats and risks, epidemic outbreaks are minor at the outset and infrastructural impact, but they develop and spread over various geographic areas rapidly. The latest pertinent examples include the MERS virus, SARS virus, Swine flu, Ebola, and the most recent one, COVID-19.

In this research, the effect of the COVID-19 pandemic on the behaviour of different retail and logistics companies was analysed based on the variation in supply and demand specifically in consumer-packaged goods (CPGs). The occurrence of a supply and demand imbalance caused by a major disruption is assessed using a multiple case study methodology, aiming to also identify the potential materialization of the bullwhip effect in the companies that participated in this study. Different actors along the supply chain were interviewed at two different stages of the pandemic to analyse behaviour while the pandemic effects were shifting. In addition, this paper also aims to identify the different risk management decisions taken to affront the pandemic to determine managerial tendencies in terms of logistics and product distribution in such a scenario.

The opportunity to evaluate this phenomenon in the Uruguayan context is key to this analysis, as contagion curves and public policies differed quite notably compared to most countries in the region, mainly in the first months of the pandemic. The government appealed to the social responsibility of citizens, and the mandatory confinement measure was not taken. These decisions, added to aggressive testing (1610 tests per new case in June 2020) and rigorous identification and monitoring of sources of contagion, resulted in the correct management and response to the pandemic [8].

The article is structured as follows. Section 2 presents a literature review in the fields of disruptive events that impact supply chains, causes and consequences of the bullwhip effect, and resiliency in supply chains. Section 3 outlines the research methodology used for this study. The results and discussion are presented in Section 4, followed by the main research conclusions in Section 5.

2. Literature review. -

2.1. Supply chain visibility and bullwhip effect. - Disruptions will, in all likelihood, cause some sort of effect either in consumer behaviour or in the ability of different parts of the supply chain to provide goods or both. A common issue with supply chains is the poor visibility upstream and downstream from a particular link in the chain [9]. Distorted information between ends of supply chains causes inefficiencies such as excessive inventory investment, poor customer service, lost revenues, misguided capacity plans, ineffective transportation, and a loss of effectiveness to comply with predefined production schedules [10].

This phenomenon is widely known as the bullwhip effect. The term was coined by Lee [10], although prior publications already established consequences of lack of visibility and poor demand forecasting. Forrester indicated that it is empirically recurrent that the variance of perceived demand to the manufacturer far exceeds the variance of consumer demand, and the effects of not being able to accurately forecast needs from intermediate players in the supply chain, as they relate to actual customer demand, are observed to be larger for manufacturers than for retailers [11]. In other words, the lack of visibility between participants in a supply chain causes minor shifts in consumer demand to result in large variations in the size of the orders that reach the manufacturers upstream in the supply chain [10, 12].

The bullwhip effect can be caused by several factors. One is demand forecast updating. Forecasting is a decision-making process that is frequently used in every link of the supply chain to predict what the demand for products will be. The combination of inconsistent demand signals, due to different disruptions such as price fluctuation or natural disasters, and forecast-driven organizations that make isolated decisions along the supply chain, causes the real demand to be amplified increasingly as it moves upwards [9].

The demand forecast updating falls into another reason why the bullwhip effect occurs: the lack of communication. Misinformation both inside or outside an organization is reflected in large time lags between reception and transmission of information and deliberates into excessive inventory [11, 13]. Ultimately, the effect consists of a real fluctuation in demand which triggers a forecast-driven response in the last link of the supply chain followed by a forecast-driven response of the second link based on the former forecast and so on. The effect will be aggravated by anything that decreases forecast precision, such as long lead times, or lack of communication with the extreme case being decision-makers relying only on adjacent links' information.

Moreover, order batching is an additional factor that magnifies the bullwhip effect. There are two ways of order batching: periodic ordering, in which an order is placed after a specific period (weekly, monthly, etc), or push ordering, in which the products are ordered prematurely expecting to modify or affect the customers' behaviour [10]. The batching of orders induces demand variance up the supply chain that is not present at lower levels of the chain. Furthermore, order batching can delay orders and thus hinder information flow throughout the supply chain making them less responsive [11].

Rationing and shortage gaming is a managerial resource when demand exceeds supply. If there are not enough products to satisfy customers' requirements, fractioning the number of products available is an existing alternative. In this case, the customers' orders will be excessive in reaction to this shortage and may not reflect the product's real demand to the manufacturer, leading to the bullwhip effect [10].

A system must be well prepared to cope with these imbalances to ensure continued operation and to survive in a world in which supply chains extend throughout the globe [14].

2.2 Supply chain risk management. - To mitigate the disruptions´ effects, or avoid them altogether, supply chain risk management (SCRM) comes into play. SCRM can be defined as ‘‘the management of supply chain risks through coordination or collaboration among the supply chain partners to ensure profitability and continuity’’ [15]. For industries that are moving towards longer and more interconnected supply chains (e.g., outsourcing) and facing an increasingly uncertain demand and supply, risk management is vital. As supply chains go leaner and more integrated, it is more probable that accidents in one link of the chain affect the others [16].

The SCRM consists of four key stages: risk identification, assessment, treatment, and monitoring. These four stages are developed by the internal implementation of tools, techniques, and strategies. It also consists of external coordination and collaboration with supply chain members to reduce vulnerability and ensure continuity coupled with profitability, leading to a competitive advantage in adverse situations [17].

2.3 Resilience in supply chains. - Disruptive events and the materialization of the bullwhip effect can directly affect the ordinary activity of companies. External shocks to supply chains that are not optimized to mitigate these situations can cause disruptions that are several orders of magnitude larger than the disruption itself. The resilience of a supply chain can be considered as “its ability to reduce the probabilities of facing a disruption, the consequences of those disruptions once they occur, and the time to recover normal performance” [18]. An additional concept that refers to the adaptability of a supply chain is robustness. Robustness is the ability to continue with operations and to maintain the level of service while sailing through internal or external disruptions [19].

Once a disruption has occurred, the primary source of uncertainty for managers is the demand for products. Hence, the ability to respond to the variability of the demand in disruptive events is tightly associated with resilience [6]. Three kinds of capabilities can lead organizations to be resilient: (1) flexibility, which refers to a quick ability to evaluate and take needs into account responding to end consumers; (2) integration capabilities, which refer to the degree to which a manufacturer strategically collaborates with its supply chain partners and collaboratively manages intra and inter-organizational processes and (3) external capabilities that relate to the collaboration through systems such as Vendor Managed Inventory (VMI) and Collaborative, Planning, Forecasting, and Replenishment (CPFR) with retailers to enhance close cooperation among autonomous organizations engaged in joint efforts to effectively meet end-customer needs [20].

When talking about resilience and robustness of supply chains, it is assumed that the ability to manage risk and to take accurate decisions leads to a better positioning vis a vis competitor to deal with disruptions and, also, to try to take advantage of the adverse situation, to act as a potential source of competitive advantage [21]. In particular, having a vast range of suppliers and preventing or avoiding risks were identified as vital factors to ensure resilience [22].

The planning decisions taken under the demand uncertainty of a supply chain caused by a specific disruption are fundamentally taken to maximize its economic performance. Planning decisions are related to the determination of production rates, inventory levels, forward and reverse flow amounts, and transportation links. These decisions involve actors such as consumers, supermarkets, stores, offices, distribution centres, and factories. In that way, both resilient freight transportation and an effective communication system are critical to standing against disruptions [23, 24, 25].

Moreover, when facing a pandemic situation, the daily monitoring of global suppliers plays an important role due to the perceived fluctuations and the demand uncertainty. New technologies, such as artificial intelligence and natural-language processing, permit extensive supplier monitoring [26].

2.4 Research gap. - With the world facing the COVID-19 pandemic, an opportunity is presented to analyse the effects of disruption with a scale and reach that has not occurred in the era of globalized global spanning supply chains. This setting is putting enormous pressure on supply chain managers to cope with demand and supply for their companies to be able to survive the disruption in the best way possible. The deep implications of the decisions being made by governments and the uncertainty of the duration of the disruption call for analysis of the effects that supply chains are suffering and what they are doing and planning to do in the future.
Even though there have been worldwide pandemic disruptions in recent decades, none of them has had such a high score both in transmutability and clinical severity as the COVID-19 pandemic when measured with the Pandemic Severity Assessment Framework. For a similar event in severity, we need to reach as far back as 1918 for the Spanish flu pandemic [27]. The world has changed immensely since then, and thus research regarding the situation is valuable.
Moreover, studying the phenomenon in Uruguay is a unique opportunity to study the influence of demand's behaviour and economic shock impact on the reactions of supply chains and their resiliency in a developing country. Valuable information could be obtained to identify strengths and weaknesses displayed by the supply chains as well as to evaluate different measures and decisions made during the first months of the COVID-19 disruption.

3 Methodology. - A multiple case study was undertaken to analyse the impact caused by the COVID-19 on Montevideo´s supply chains during the first four months of the pandemic. To understand the decisions that relevant retail and logistics´ actors had taken, and to understand the reasons for their attitudes and opinions, it was necessary to carry out a qualitative analysis [28]. As the event of the global pandemic had no previous precedent and the entire world was affected, new problems and conflictive situations appeared daily. To face this phenomenon, managers had to constantly make decisions to respond to the fluctuating demand of the market and the unexpected changing in policies and lockdowns. In this case, it was considered relevant to cover contextual conditions by the establishment of personal contact as it was considered strongly pertinent to the phenomenon of study [28, 29].

There are three different methodological approaches to case research: theory generation, theory testing, and theory elaboration [30]. This study was conducted through theory testing. It was expected, for example, that the supply and demand of some specific products responded to the bullwhip effect and, therefore, the different actors within the supply chain would react in consequence. In theory-testing case research, the general theory is contextualized before subjecting it to the empirical test. Moreover, the case study propositions come situationally grounded already in the theory phase of research [30].

For case studies, theory development as part of the design phase is essential, whether the ensuing case study's purpose is to develop or test theory [29]. The case study of the COVID-19 situation is classified as embedded (multiple units of analysis) and multiple-case design because multiple periods (different contexts) and several cases within each period (different companies) were considered to observe several measures and reactions to the affronted crisis.

Regarding the construction of the interviews, the scope of the interviews was defined first, and the theory was developed to gather valid and reliable data relevant to the research [28]. The research aimed to study the effect of COVID-19 on the behaviour of different production, distribution, and wholesale companies in Uruguay. In this line, the objective of undertaking interviews was to observe and understand the reactions and decisions taken by the operation and logistic managers due to the pandemic situation.

In this way, it was decided to complete two rounds of interviews to study the supply chain reactions to the pandemic at different stages of the global disease in the country. The first round of interviews was executed in March 2020, within the first four weeks of the arrival of the pandemic in Uruguay, to observe and study the first supply chain reactions. The second round was performed during the third and fourth months after the first COVID-19 case in Uruguay was diagnosed. This round of interviews allowed us to analyse the situation in a clearer and more stable context regarding the pandemic.

The theory to prove considered three points to analyse. In the first place, the influence of the pandemic outbreaks leading to important disruptions in terms of the presence of long-term and unexpected scaling disruption, propagation of the virus in the population, and disruptions in the development of logistics, demand and supply was studied. Secondly, these affectations were deepened to observe the variations in the consumer's behaviour due to the pandemic and how those variations lead to diminishing the businesses' visibility disemboguing in a bullwhip effect situation. Thirdly, the capacity of businesses to be resilient and the importance of coordination among the supply chain to succeed were tested.

Furthermore, both interviews were designed to test the theory. There are different kinds of qualitative research strategies and they can be classified by the type of questions being asked. Generally, what questions may either be exploratory or about prevalence, in which surveys or the analysis of archival records would be favoured. Moreover, how and why questions are likely to favour the use of case studies, experiments, or histories [29]. In the case of the impact caused by COVID-19, it is relevant to observe businesses' reactions and behaviour. In this way, it is relevant to ask what, how, and why questions. The framework and the questions asked in the interviews are presented in Figure I.

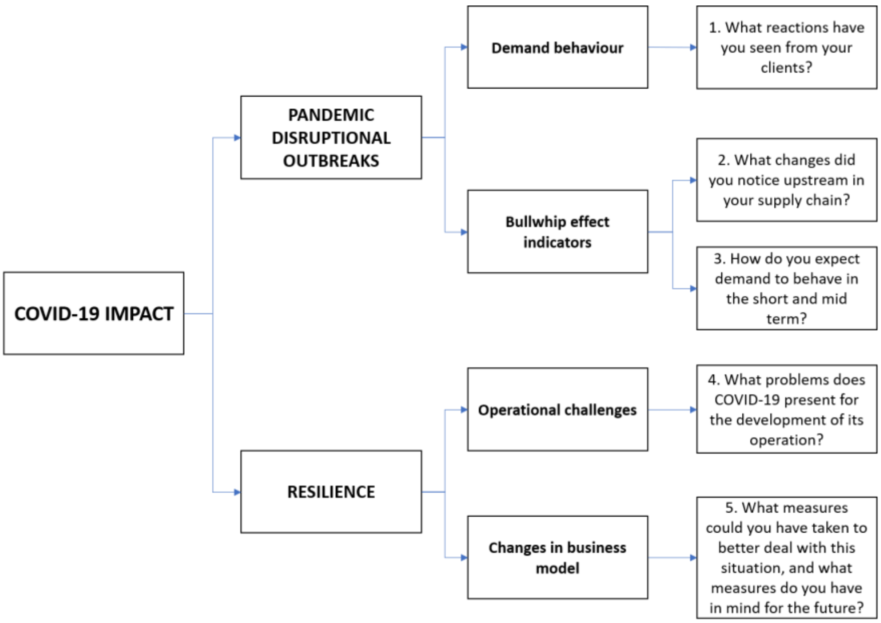

Figure I - 1st round Interview framework

In terms of the execution, the first round of interviews was completed in the first four weeks of the COVID-19 pandemic. Fourteen managers of fourteen different organizations from the CPGs channels of foods, pharmaceuticals, personal hygiene products and fashion were included in the study. The set of interviewed businesses ranges from manufacturing to transportation service companies.

Business area	Number of managers interviewed
Urban Goods Distribution and logistics	4
Food manufacturers and importers	6
Department stores and supermarket chains	1
Pharmaceutic store chains	1
Textile and clothing sector	1
Tissue paper manufacturer	1

Table I - Number of managers interviewed by business area

Once the interviews were fully transcribed, the mass of qualitative data collected was structured into meaningful and related patterns or categories to explore and analyse the data systematically and rigorously. Interpreting qualitative information is, to a great extent, a challenge in making sense of chaos. A useful technique to see an order from chaos involves structuring the data in a variety of patterns [28, 31]. The generated coding structure is stated in Table II.

<table>
<tr><td rowspan="9">1. Pandemic outbreak disruption</td><td rowspan="6">1.1. Disruption risks</td><td>1.1.1. Difficulty to forecast demand</td></tr>
<tr><td>1.1.2. Migration of consumers to residential areas</td></tr>
<tr><td>1.1.3. Decrease in general economic activity</td></tr>
<tr><td>1.1.4. Irrational demand</td></tr>
<tr><td>1.1.5. Uncertainty regarding the chain of payments</td></tr>
<tr><td>1.1.6. Price uncertainty</td></tr>
<tr><td rowspan="2">1.2. Operational risks</td><td>1.2.1. Adoption of protection measures</td></tr>
<tr><td>1.2.2. Reduction of staff and working hours</td></tr>
<tr><td>1.3. Coordination in supply chain</td><td>1.3.1. Response to demand</td></tr>
<tr><td rowspan="5">2. Bullwhip effect</td><td rowspan="3">2.1. Causes</td><td>2.1.1. Low visibility</td></tr>
<tr><td>2.1.2. Changes in demand</td></tr>
<tr><td>2.1.3. Human feelings involved</td></tr>
<tr><td rowspan="2">2.2. Consequences</td><td>2.2.1. Breach of orders</td></tr>
<tr><td>2.2.2. Portfolio reduction</td></tr>
<tr><td rowspan="8">3. Resilience</td><td rowspan="2">3.1. Importance of a resilient SC</td><td>3.1.1. Variety of providers</td></tr>
<tr><td>3.1.2. Prevention</td></tr>
<tr><td rowspan="4">3.2. Actions to adapt and take advantage of the crisis</td><td>3.2.1. Diversify channels and portfolio</td></tr>
<tr><td>3.2.2. Decision making according to government recommendations</td></tr>
<tr><td>3.2.3. Improve the quality of service</td></tr>
<tr><td>3.2.4. Local suppliers</td></tr>
<tr><td rowspan="2">3.3. Benefits of having a resilient freight transportation link</td><td>3.3.1. Optimize truck frequencies</td></tr>
<tr><td>3.3.2. Logistics of new sales channels</td></tr>
</table>

Table II – Coding structure

The template analysis involved categorizing and unitizing data. The information was coded and analysed to identify and explore themes, patterns, and relationships. The template approach allowed codes and categories to be shown hierarchically to help the analytical process. The process of analysing interview transcripts or observation notes led to some of the codes being revised and even changes to their place or level in the template hierarchy. [28]. After the execution of the first round of interviews, the pandemic situation began to stabilize in Montevideo and the second round of interviews was designed.

The questions included in the second round were adapted to observe the behaviour of the supply chain, making the focus on those points identified after the first round of interviews. The execution of the second round of interviews was completed in the third and fourth months after the diagnosis of Uruguay's patient zero. The same fourteen actors from the specific CPGs channels of foods, pharmaceuticals, personal hygiene products, and fashion were contacted. However, one of the actors was impossible to contact and, finally, the second batch consisted of thirteen interviews.

Once the second batch of interviews was fully transcribed, the mass of qualitative data collected was structured and analysed. The same framework utilized for the first round of interviews was used to develop the coding structure and to analyse the results of the second round.

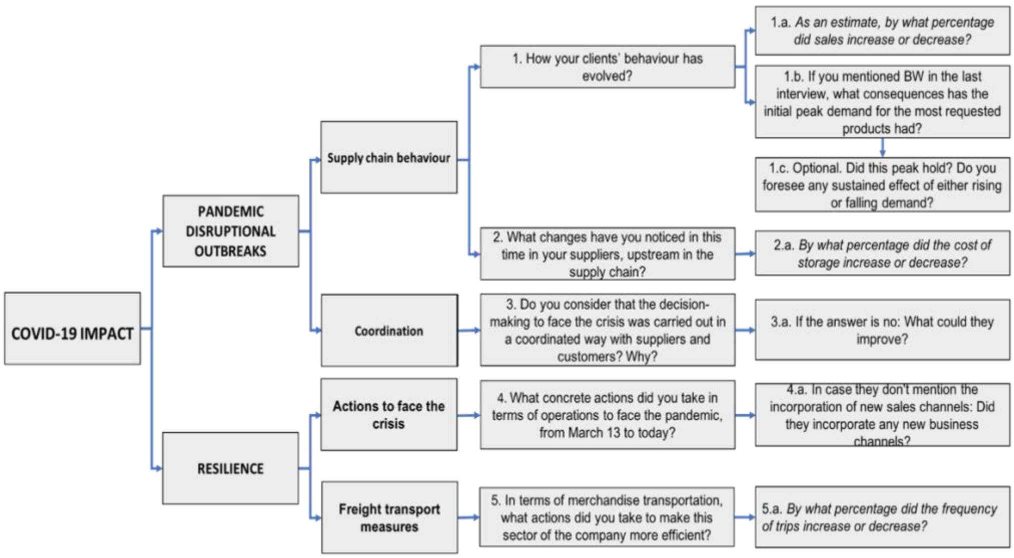

Figure II – 2nd round Interview framework

4 Results and Discussion. - On the demand end of the supply chain, a shock in demand caused by fright buying was initially observed. According to one of the interviewees, in the first days of the pandemic "the reaction was panic, due to the situation of a possible quarantine. This automatically led to a substantial increase in the demand for CPGs". This in turn put supply chains relying on "Just in Time" methodologies under considerable pressure and the sight of empty shelves became normal.

4.1 Pandemic outbreak disruption. - In terms of disruption risks caused by the COVID-19 outbreak, one of the main problems observed was the difficulty in accurately forecasting the consumers' behaviour in the first weeks of the pandemic [1]. This forecasting problem turned into uncertainty about the demand´s behaviour, which restricted management's capacity to make operational decisions to accurately balance supply and demand.

The principal difficulty to forecast the consumers' behaviour lay in the irrational consumer behaviour during the initial moments of the pandemic. One of the interviewees mentioned that during the first pandemic days: "We have very unstable demand parameters and that makes planning substantially difficult since it is not possible to determine what was going to be delivered the next day. The level of demand observed these days is not normal and it is changing day by day, so we must adapt daily to meet delivery orders".

This was reflected in specific peaks of consumption, especially in CPGs and personal care products, to avoid potential shortages of items perceived to be of first need. Although in Uruguay the COVID-19 outbreak was not so critical during the first months compared to other countries, the first social reaction was panic, because of the possibility of a national quarantine status, which automatically lead to a substantial increase in the demand for CPGs and personal care products. In the second round of interviews, it was perceived that the demand stabilized.

PANDEMIC OUTBREAK DISRUPTION		Number of mentions in the first round of interviews (within the first month from patient zero)	Number of mentions in the second round of interviews (3 to 4 months after patient zero)
Disruption risks	Difficulty to forecast demand	12	-
	Migration of consumers to residential areas	11	1
	Decrease in general economic activity	10	3
	Irrational behaviour	9	-
	Uncertainty regarding the chain of payments	4	2
	Price uncertainty	1	2
Operational risks	Adoption of personal protection measures	10	13
	Reduction of staff and working hours	9	5
Coordination in supply chain	Response to demand	3	9

Table III - Pandemic outbreak disruptions interview coding

Faced with the unexpected and constantly changing demand situation, companies engaged in manufacturing, import, and distribution of goods commented to have experienced a "survival" mode to meet the operational needs. One of the main difficulties was the migration of consumers to residential areas and the problem of the general decrease in economic activity. Even though there was not a strict quarantine declaration in Uruguay, the government strongly encouraged citizens to remain in their houses. This governmental recommendation had an impact on the migration of the population's activity to residential areas.

This measure impacted negatively on the businesses located in centric and working areas, as fewer customers frequented their stores, and some of them had to close entirely, either temporally or definitively. One of the interviewees contributed: "The activity varied according to the area of the city, given that in residential neighbourhoods the activity increased. In downtown areas where there is a concentration of offices and public spaces where social activity fell, a consequent drop in merchandise distribution was observed, unlike in residential neighbourhoods".

Department stores and supermarkets located in residential areas perceived an uprise in their demand, as customers visited the stores more frequently, and bought higher volumes per visit. The supermarket chain operations manager stated: "It was a sudden change from one day to the next. Of course, some products were stocked out, not because there were problems in the supply channel, but because the demand doubled from one day to the next. The first weeks were chaotic, fights were detected over certain products in stores".

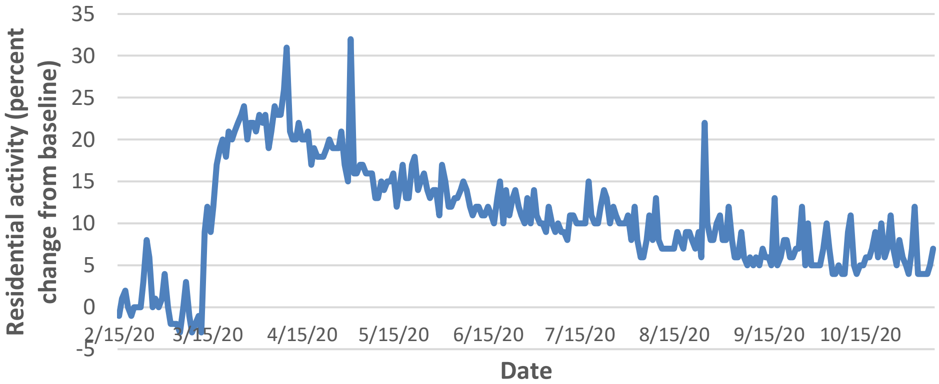

Figure III - Social behaviour in Montevideo (Source: Google LLC "Google COVID-19 Community Mobility Reports")

In terms of perception of a general decrease in economic activity, except for some specific product channels, a general decrease in demand was noticed. The main causes of this decline were the migration of consumers toward essential and basic products and the reduction of people's purchasing ability due to the crisis. As months went by, the loss of income for the average consumer became clear. The interviewees mentioned that a considerable drop was noted in the level of sales.

Moreover, distribution was strongly affected by the drop in the activity of micro, small and medium enterprises (MSMEs) which represented a significant percentage of the customers of the logistics companies that participated in the study. MSMEs were the businesses that were hit particularly hard by the pandemic, due to their reduced scale and low capacity to adapt to abrupt changes. To some extent, MSMEs experienced a reduction in the supply of labour, their ability to function was constrained and they experienced severe liquidity shortages due to a dramatic and sudden loss of demand and revenue [3]. Despite the sudden increase in the volume ordered by supermarket chains during the first weeks, the MSMEs' situation impacted directly the reduction of general supply activity.

Lastly, retailers tended to ask for higher credits from wholesalers, caused by uncertainty of the significant slump in the customers' revenues caused by the pandemic, which resulted in an important delay of the payments cycle. This condition augmented the difficulty to manage the company and increased the risk of going bankrupt, causing a considerable amount of businesses to close their doors.

Overall, the principal disruption risks observed were difficult to forecast demand during the first weeks of the pandemic which turned into uncertainty about the demand´s behaviour and restricted management's capacity to make operational decisions. The situation stabilized and in the second round of interviews, this disruption risk was not mentioned.

The main cause of the difficulty to forecast demand was the irrational consumer behaviour during the initial moments of the pandemic. This irrational consumers' attitude was specifically spotted during the first weeks of the pandemic. In the second round of interviews, the observed "new normality" caused changes in customers' behaviour, yet explainable and manageable when making decisions within the supply chain.

In addition, a decrease in the general economic activity was attributed by the interviewees to the migration of consumers towards essential and basic products, and the reduction of people's purchasing ability due to the crisis. The contacted companies' sales levels, although they increased in some specific sectors such as essential products that refer to personal care and hygiene according to the pandemic, generally dropped.

Operational risks were mainly related to the adoption of operational changes to adjust to the COVID-19 situation. Public health measures such as self-isolation and movement restrictions in addition to actual COVID-19 cases among the workforce posed an uncertain scenario not only for manufacturers but also for transportation and distribution networks. Extra resources have been put in place to implement contingency plans to mitigate risks. Furthermore, international trade has been affected by "thicker borders" [32], impacting all products that have imported components.

All running businesses had to implement personal protection measures to make sure their workers and customers were safe to continue operating. Specific actions such as adaptation of the work shifts, spacious workplaces, providing workers with facemasks, gloves, sanitiser, sanitation spots with soap to wash their hands, training sessions to understand the seriousness of the matter, and contingency plans in case of contagion were undertaken. Another action taken to reduce contact was to carry out remote selling and avoid visiting customers.

This adoption of specific measures taken to guarantee personal protection was highly mentioned in both rounds of interviews. Moreover, in the second round of interviews, in which the demand situation and production and logistics activities had stabilized, it can be seen that the sanitary and protection measures embraced were, in some way, motivators of such stability.

Furthermore, personnel and workload shortcuts were identified as operational risks. The decrease in general demand, and the financial hit caused by the crisis, lead to an important reduction in working activity. In this aspect, some companies decided to reduce the personnel and the workload. For example, numerous companies were affected directly by the decrease in the sales capacity, leading to a reduction in the company's structure in the commercial sector. At the operations level, some had to reduce personnel to lessen the preparation and delivery capacity. Finally, at the administrative level, the same happened. The general reduction of the economic activity generated reductions in the companies' structures in terms of personnel and time.

Finally, to stand against the suffered crisis, the coordination between the supply chain actors is considered substantial. Even though uncertainty levels were high in the first weeks of the outbreak, and no prediction of the near future could be made, many companies made decisions without sufficient coordination among other impacted links of the supply chain. For example, due to the excessive demand for sanitation products, imported product flow was shortened as external companies strategically decided to supply their country's demand and reduce product export. In one of the interviews, it was mentioned that during the first moments it was difficult to coordinate within the supply chain not because there was no communication, but because of the level of uncertainty at hand.

Moreover, the pandemic situation caused a global impact and all the links in the supply chain were aware of it. Some of the interviewees mentioned that there was more coordination now than before the pandemic, as it favoured the growth of communication. One of the managers from a food distributor commented that they had the objective to not cut the food supply. To guarantee the delivery and service with the suppliers that the communication presented a greater complexity, a more intensive communication was used: “For the links that are more resistant to communication, our team was in charge of frequently contacting the different managers to generate that flow of information”.

One of the interviewees catalogued the COVID-19 as a new problem that was summed to the habitual problems in supply themes: “We have an effective communication system regardless of this specific topic: COVID-19. This is one more issue that adds to the usual ones, there will always be problems to solve”.

The pandemic was an opportunity for some companies to work collaboratively. In general terms, in the first round of interviews, it was observed that collaboration between the different links of the supply chain was scarce. However, in the second round of interviews, a higher level of coordination upstream and downstream in the supply chain was mentioned.

4.2 Bullwhip effect. - Some specific sectors experienced an exponential rise in demand that led to shortages and the necessity to take important decisions to adapt their distribution plans. The main sectors that perceived an increase in demand in the first weeks of the pandemic were cleaning, personal hygiene, and food products. This increase was attributed to the declared sanitary emergency by the government, to the motivation to adopt personal care measures due to the ease of contagion presented by the virus, and finally to the imminent threat of compulsory lockdown.

A misperception of excessive demand increase was perceived by suppliers, which was caused by this sharp and sudden upgrowth in demand on the side of retailers (and a consequent placement of excessive orders to suppliers), together with the buyer's tendency to over-supply in anticipation of a possible total quarantine. This tendency, known as panic buying [33], distorts suppliers´ demand perception, is frequently observed in disruptions and natural disasters, and causes inventory struggles.

According to literature, this phenomenon is called the bullwhip effect and it can lead to severe consequences for the businesses’ development in terms of inventory, operations, and logistics management [12]. One of the interviewees mentioned that a sudden peak in demand was perceived, especially in the area of personal care and household hygiene products. The first fifteen days were complex in aligning demand with capabilities and the demand exceeded the capacity several times.

BULLWHIP EFFECT		Number of mentions in the first round of interviews (within the first month from patient zero)	Number of mentions in the second round of interviews (3 to 4 months after patient zero)
Causes	Low visibility	12	4
	Changes in demand	9	13
	Human feelings involved	3	3
Consequences	Breach of orders	5	3
	Portfolio modification	2	3

Table IV - Bullwhip effect interview coding

The factories, importers, and wholesale companies that took part in the study mentioned that, during the first fifteen days of the pandemic, they did not have real visibility of end-customer demand, but an exaggerated version produced by their downstream customers. The shortage of customers and the consequently reduced sales paired with the erratic behaviour of participants in the supply chain led to highly variable production schemes in factories and high inventory costs. In terms of personal care, household hygiene, and some essential food products the bullwhip effect was definitively observed, and the different companies had to adapt and respond to a variable and unexpected demand.

An example of this phenomenon could be seen in one of the interviews with a manager of a bathroom tissue factory at the beginning of this pandemic. Toilet tissue, being a product with a low price-to-volume ratio causes merchants generally not to hold large inventories, and the supply chain tends to be tight and efficient. When the first cases of COVID-19 appeared in Uruguay, the demand exceeded the production found in the stocks of the selling companies, even though the physiological needs of the people did not change due to the pandemic.

The increase in demand for household products was almost instantaneous, and the shortage of stores caused the public to over-supply. This peak in demand caused retailers and distributors to demand a significantly larger stock of inventory than usual. In response, the factory ceased to produce a wide range of products and focused instead its production schemes towards the most demanded products.

However, the increase in demand for these specific items did not continue indefinitely. These peaks were clear in the second half of March and some localized peaks in April, causing stock problems as the industry was not prepared to supply the present demand.

Another effect that allows determining that the bullwhip effect occurred was the human feelings being involved in decision-making processes [10]. The shocking situation caused fear and desperation in society, mainly associated with the fact that there was no historical record of such a global pandemic, and it was impossible to predict the progress of contagion. These feelings, when present in decisions, distort real demand numbers and snowball through the supply chain causing inventory struggles and misuse of production capacities. In the first round of interviews, it was said that this kind of crisis generates nervousness in all areas, causing excessive decision-making or a lack of prudence in situations of tension.

In terms of the consequences of the bullwhip effect, the breach of orders and the portfolio reduction, which are considered consequences of the bullwhip effect [10], were identified.

As retailers perceived an extremely high demand in an exceedingly short time, they had to prioritize clients and concentrate on certain channels to supply these regularly. Companies that delivered healthcare products and basic foods experienced an extremely high demand in a short time, for which they had to prioritize clients and channels, to define whom to deliver to supply all channels as far as possible.

Regarding portfolio reduction, some companies generated a list of a few dozen critical articles that strictly have to do with the needs related to the COVID-19. Other companies reduced their products catalogue and adopted a push selling strategy with the remaining products. For instance, one of the interviewees mentioned that they “went from forty-four to less than half of the product codes, and sales are being concentrated on those products, guiding customers to buy those specific products”.

To sum up, the bullwhip effect was identified during the first four weeks after the first COVID-19 case in Uruguay, and consequences were perceived. Low visibility of demand, changes in consumption, and the influence of human feelings in critical situations were observed. The product brunches that suffered the bullwhip effect were personal care and household hygiene and basic foods. According to the interviewees, these kinds of products were considered indispensable by customers to overcome the pandemic and, consequently, people overstocked, leading companies to struggle against shortages and excessive orders.

4.3 Resilience. - Finally, in terms of resilience and robustness in the situation of the COVID-19 pandemic, three important aspects were assessed: the importance of a resilient supply chain to respond to the crisis, actions to adapt and take advantage of the crisis, and the benefits of having a resilient freight transportation link [19, 22].

RESILIENCE		Number of mentions in the first round of interviews (within the first month from patient zero)	Number of mentions in the second round of interviews (3 to 4 months after patient zero)
Importance of a resilient SC	Variety of suppliers	5	4
	Prevention	3	4
Actions to adapt and take advantage of the crisis	Diversify channels	6	6
	Decision making according to government recommendations	4	8
	Improve the quality of service	3	3
	Local suppliers	2	1
Benefits of having a resilient freight transportation link	Optimize truck frequencies	2	5
	Logistics of new sales channels	2	6

Table V – Resilience interview coding

Resilience and robustness were critical characteristics that organizations had to show to survive and even take advantage of this crisis. Particularly, having a vast range of suppliers and preventing or avoiding risks were identified by interviewees in both rounds of interviews as vital factors to ensure resilience. One of the interviewees mentioned in both rounds of interviews that the benefit of having a variety of strong suppliers in different product channels resides in the fact that, in case of disruptions, some of them may fall, but others will stand or grow and stabilize the economic activity of the business.

Furthermore, developing risk mitigation plans such as considering local suppliers (higher costs but lower lead times) and investing in online channels were remarked prevention strategies to affront the crisis between the interviewed companies.
To evaluate resilience, the actions taken to adapt and take advantage of the crisis were analysed. The most frequent action was the decision to diversify sales channels. Due to the reduction in commercial activity, companies were forced to adopt new distribution and commercial practices. For instance, a vast number of businesses started or accelerated their development on delivery or non-personal channels, to avoid contact and possible contagion or to gain access to clients that migrated to residential areas [34].

One of the interviewees noticed that: "We migrate to the use of the website, the generation of product baskets, to that type of variants that allow us to reach the final consumer which we cannot reach by other means". The interviewed companies migrated to familiar formats and product baskets and the e-commerce channel. According to one of the interviewees "the e-commerce channel was substantially enhanced. What had grown in 3 or 4 years, doubled in 2 months".

Furthermore, another observation from the interviews was the influence of governmental recommendations on business decision-making. In the case of Uruguay, the government proposed a new format of partial unemployment insurance and some companies decided to follow this proposal so as not to fire people or send full unemployment insurance. Being COVID-19 a national emergency, the government's proposals to return, step by step, to normality turned into a considerable point to take decisions and design plans to face the pandemic.

Another noted action was the improvement of the existing service due to the demand decrease. One of the interviewees commented that "to the extent that we have fewer delivery points we have improved the service as much as possible in some way given that there is a competition to win. Also, there is a service to provide the essential products at the right time and place, it is not only a business issue but a critical social issue".

In terms of the import of goods, the complexity of this activity increased due to the border restrictions with neighbouring countries. Uruguay is highly dependent on activity in Brazil and Argentina since many products are manufactured there, so border closure and reduction of working hours in neighbouring countries directly affected local supply chains.

The fact that the Uruguayan market is smaller than other countries in the region also has an influence, so importers cannot be as demanding in terms of the volume of orders. In this scenery, to reduce the risk of shortages, many companies, mainly manufacturers and distributors, turned to local suppliers as a strategic measure, even when the prices offered were not as competitive as international ones. This change of suppliers towards locals, although it normally increases the manufacturing cost, allows to shorten production and delivery times, and therefore become more sensitive to respond to the changes in demand.
It was observed that in the first round of interviews, during the first fifteen days of the pandemic in Uruguay, the low visibility and the impossibility to foretell the demand enforced the resiliency of the different companies to endure the pandemic crisis and uncertainty. This enforcement motivated resilient and robust decisions that permitted the different companies to put up with the controversial situation and to develop new business channels.

Finally, regarding the benefits of having a resilient urban distribution, two phenomena were observed. In the first place, some companies commented on the actions taken to optimize the distribution fleet frequencies. A reduction in the truck frequencies was observed, to adjust cargo and take full advantage of the available capacity per truck in the transportation of products. During the first round of interviews, it was noted that the way to respond to the decrease of the goods and lumps to deliver was to unify deliveries, reducing the frequency of vehicles. Throughout those first days, part of the transport staff did not go out on the street.

Moreover, the issue of all precautions both in the delivery and in the handling of goods was identified in the interviews. This protocolary delivery activity meant that at many points the delivery has been slowed down. One of the interviewees mentioned: "in some sectors, if you did 10-12 deliveries on the day, today you do 8. The trucks are forced to stop further away because businesses do not receive the invoice and do not allow the unloading of merchandise until the previous supplier has finished their unloading work".

On the other hand, measures to adapt the logistic activity to new sales channels were identified, particularly in the remote or online channel. One of the interviewees highlighted the necessity to have a much more efficient web order logistics, constantly adapting to customers' behaviour and evaluating the level of service that is expected. "We first looked for transportation to be effective to respond to our perceived need, and transportation was effective but very inefficient. Next, an attempt was made to improve efficiency by controlling the number of carriers, working hours, and task management, thus adjusting the transport price ratios about sales".

5. Conclusions. - The Coronavirus outbreak impacted deeply supply chains, and its disruptive nature made managerial decision-making challenging. During the first four months since the first COVID-19 case was identified in Uruguay, it is possible to conclude, in the first place, that the outbreak seriously affected the structure dimension and the operations of supply chains during the first stages of chaos and uncertainty. The high level of uncertainty generated in the first period of the pandemic, causing struggle to predict consumers' behaviour, made it essential for supply chains to enhance coordination between links, work on improving resilience and manage risks to reduce their impact and, in some cases, even take advantage of this crisis.
Particularly, the difficulty to forecast demand during the first weeks of the pandemic was perceived, which turned into uncertainty about the demand´s behaviour and restricted management's capacity to make operational decisions during those first two weeks. Moreover, the irrational consumer behaviour during the initial moments of the pandemic and the migration of consumers to residential areas were observed. In this controversial situation, businesses had to adapt and respond to overpass the pandemic situation.

In the period time studied, a decrease in the general economic activity was observed. According to the interviewees, it was attributed to the migration of consumers towards essential and basic products and the reduction of people's purchasing ability due to the crisis. The contacted companies' sales levels, although they increased in some specific sectors such as essential products that refer to personal care and hygiene according to the pandemic, generally dropped.
Several procedures to manage the identified risks due to the pandemic were implemented in the different interviewed companies. For instance, the adoption of personal protection measures and the reduction of staff and working hours were identified as a response to operational risks and were implemented to maintain production and transportation services active.

Moreover, the bullwhip effect was present in some critical channels of products, such as personal care and hygiene, and essential foods. Such a sudden peak of demand caused by both an objective necessity of sanitation or food provision, and a subjective feeling of panic or fear of stockout delivered important shortcut situations and came along with modifications at the placed orders to respond in a certain way to an unknown and variable demand. Furthermore, impacted supply chains had to enhance communication and visibility and, in some cases, reduce the product portfolio to avoid stockouts.

This disruptive event also showed supply chains how important resiliency is to adapt to the crisis and get through it in the best possible way. A survival attitude, understood as taking important day-by-day decisions during the first weeks of the pandemic, was a must. Also, some of the companies modified their sales channels to adapt to the new normality. In particular, the online channel experienced an interesting increase during the crisis, and some of the companies started to develop this commercial method or improved their past experiences with online sales. In a way, this can lay the foundations for the establishment of e-commerce as a strong sales channel.

All in all, it is essential to highlight the importance of incorporating the concepts of risk management, resilience, and robustness into day-to-day operations to face the different problems occurring daily in supply chain management. This research provides deep insights observed in the first months of this disruption and offers companies considerations to bear in mind when making decisions within this kind of event. In that way, it would be possible to face adverse situations in a coordinated and effective way, along the supply chain to respond to demand fluctuations.

This study is limited principally by the time-lapse in which the interviews were developed and by the constrained number of interviewed businesses. It may not be fully representative of the global situation of the COVID-19, but it may apply to developing countries in which the pandemic was successfully controlled and in which the mandatory quarantine was not established.

Further research about risk management, resilience, and robustness of the supply chain should be carried out on understanding good practices and effective strategies to respond to the pandemic. The concept of success in terms of businesses overcoming this disruption is directly linked to sustainability and resilience, so time has to pass to see clearer successful measures. As it is a unique pandemic situation, which had no registered precedents, it is fundamental to generate scientific knowledge on how to respond to future similar scenarios in case they exist.

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Learning for Optimization with Virtual Savant

Aprendizaje para la optimización con Savant Virtual

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Summary. - Optimization problems arising in multiple fields of study demand efficient algorithms that can exploit modern parallel computing platforms. The remarkable development of machine learning offers an opportunity to incorporate learning into optimization algorithms to efficiently solve large and complex problems. This article explores Virtual Savant, a paradigm that combines machine learning and parallel computing to solve optimization problems. Virtual Savant is inspired in the Savant Syndrome, a mental condition where patients excel at a specific ability far above the average. In analogy to the Savant Syndrome, Virtual Savant extracts patterns from previously-solved instances to learn how to solve a given problem in a massively-parallel fashion. In this article, Virtual Savant is applied to three optimization problems related to software engineering, task scheduling, and public transportation. The efficacy of Virtual Savant is evaluated in different computing platforms and the experimental results are compared against exact and approximate solutions for both synthetic and realistic instances of the studied problems. Results show that Virtual Savant can find accurate solutions, effectively scale in the problem dimension, and take advantage of the availability of multiple computing resources.

Keywords: machine learning; optimization; next release problem; heterogeneous computing scheduling problem; bus synchronization problem.

Resumen. - *Los problemas de optimización que surgen en múltiples campos de estudio demandan algoritmos eficientes que puedan explotar las plataformas modernas de computación paralela. El notable desarrollo del aprendizaje automático ofrece la oportunidad de incorporar el aprendizaje en algoritmos de optimización para resolver problemas complejos y de grandes dimensiones de manera eficiente. Este artículo explora Savant Virtual, un paradigma que combina aprendizaje automático y computación paralela para resolver problemas de optimización. Savant Virtual está inspirado en el Síndrome de Savant, una condición mental en la que los pacientes se destacan en una habilidad específica muy por encima del promedio. En analogía con el Síndrome de Savant, Savant Virtual extrae patrones de instancias previamente resueltas para aprender a resolver un determinado problema de optimización de forma masivamente paralela. En este artículo, Savant Virtual se aplica a tres problemas de optimización relacionados con la ingeniería de software, la planificación de tareas y el transporte público. La eficacia de Savant Virtual se evalúa en diferentes plataformas informáticas y los resultados se comparan con soluciones exactas y aproximadas para instancias tanto sintéticas como realistas de los problemas estudiados. Los resultados muestran que Savant Virtual puede encontrar soluciones precisas, escalar eficazmente en la dimensión del problema y aprovechar la disponibilidad de múltiples recursos de cómputo.*

Palabras Clave: *aprendizaje automático; optimización; problema del próximo lanzamiento; planificación en sistemas de cómputo heterogéneos; problema de sincronización de autobuses.*

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1. Introduction. - The increasing complexity of optimization problems arising in different fields of study requires algorithms that demand large computing resources [1]. Simultaneously, parallel computing has become a key piece in scientific computing, as it provides the resources needed to solve complex real-world problems that cannot be addressed using classic sequential systems [2]. Consequently, widespread parallel architectures have led to an increase in the adoption of parallel algorithms that can take advantage of the availability of multiple computing resources.

Software developers need to implement parallel programs to take profit from current architectures. This requires highly-skilled programmers that can design parallel programs from scratch or redesign legacy sequential implementations to profit from modern parallel architectures. Thus, there is an increased interest in techniques that can automatically generate elastic programs that can fully exploit highly-parallel computer platforms and scale in the number of computing resources [3]. The current growing interest in machine learning techniques comes at hand to deal with this problem.

The fields of optimization and machine learning are closely related. However, the vast majority of research has explored one direction of this relationship, i.e., optimization applied to machine learning techniques (e.g., parameter optimization in machine learning models, feature selection problems) [4]. The inverse, i.e., applying machine learning to solve optimization problems, while explored [5,6], still has plenty of room for contribution.

This article deals with VS, a novel paradigm that takes advantage of machine learning and parallel computing to address complex optimization problems [7]. VS is inspired in the Savant Syndrome, a mental condition where patients excel at certain abilities far above the average. In analogy to the Savant Syndrome, VS uses machine learning to find patterns that allow solving the problem at hand. These patterns are learned from a set of previously-solved instances of the problem. Due to its design, VS can be executed in massively-parallel computing architectures, significantly reducing execution times and effectively scaling in the problem instance.

The remainder of this document is organized as follows. Section 2 outlines the VS paradigm. Then, Section 3 presents the application and experimental evaluation of VS when solving three optimization problems. Finally, Section 4 presents the main conclusions and lines of future work.

2. Learning for optimization: Virtual Savant. - The Savant Syndrome is a rare mental condition where patients with significant mental disabilities develop certain abilities far above what would be considered average [8]. Patients with Savant Syndrome—known as savants—usually excel at a single specific activity, generally related to memory, rapid calculation, or artistic abilities. The main hypotheses state that savants learn through pattern recognition [9,10], solving problems without understanding their underlying principles.

VS is a novel technique, inspired by the Savant Syndrome, that aims to learn how to solve a given optimization problem [7]. As an analogy to the Savant Syndrome, VS proposes using machine learning techniques to find patterns that allow solving the problem at hand. These patterns are learned from a set of problem instances previously solved by one (or several) reference algorithm(s) for the problem. VS does not require knowing the code of the reference algorithms it learns from, in the same way that real-life savants are unaware of the underlying principles related to their skill. The training of VS involves partitioning the problem instance, and like savants, VS can derive global solutions by combining smaller pieces.

VS is trained using previously-solved problem instances. Learning is solely based on the input (i.e., the problem instance) and the output (i.e., the solution) computed by one or several reference algorithms. Each solved problem instance yields as many training examples as variables in the problem being solved. Once the training set is generated, a supervised machine learning model is trained over that set.

After training, VS can solve new—unseen—problem instances by following a two-phase process comprised of prediction and improvement. In the prediction phase, the trained classifier is used to predict a solution to a new, unseen, problem instance. The output of the prediction phase is a probability distribution $P(\hat{y}^i)$ for each of the i variables in the problem. The improvement phase involves generating multiple candidate solutions following those probability distributions $P(\hat{y}^i)$. Each of these candidate solutions are refined using search procedures and heuristics (e.g., local search, greedy heuristic). Corrective functions may be included in the improvement operator to ensure that the returned solution satisfies all problem constraints. Finally, all solutions are gathered, and the best overall solution is returned.

Thanks to its design, VS can be run in a massively-parallel fashion. In the prediction phase, predictions can be made in parallel by using multiple copies of the same trained classifier, since each element in the problem is learned independently. After label probabilities are computed for each variable, multiple candidate solutions can be built and improved in parallel. Thus, VS can take advantage of available computing resources to improve its search of the solution space, leading to better solutions. Figure I outlines the complete workflow of VS when running in parallel.

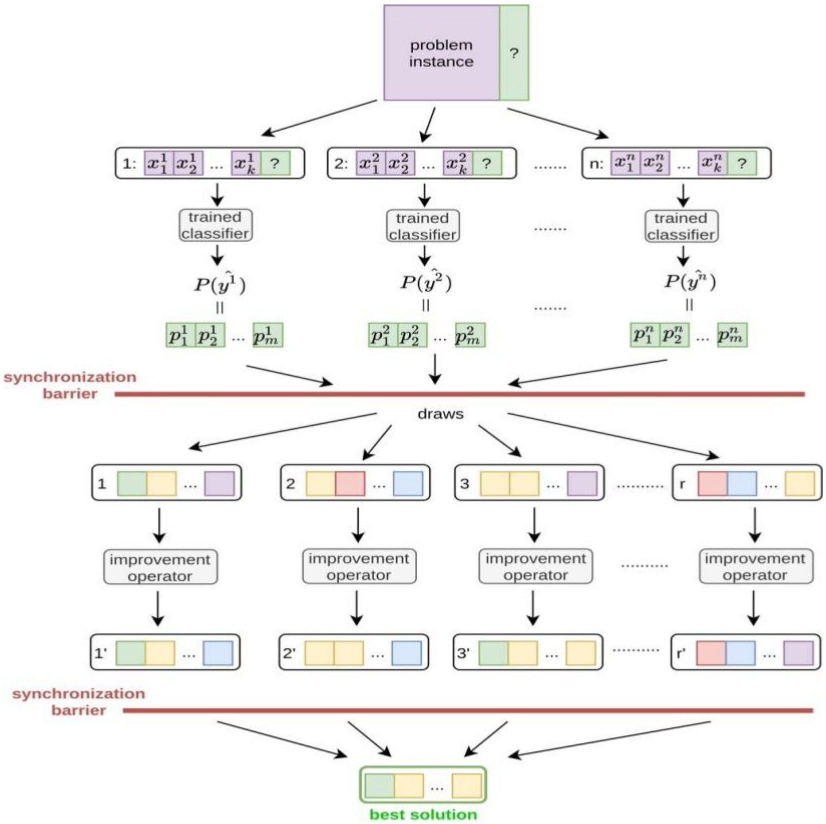

Figure I. Parallel VS workflow.

3. Applications of Virtual Savant. - This section describes the application and experimental analysis of VS over three optimization problems.

3.1. Next Release Problem. - The Next Release Problem (NRP) is a problem in Software Engineering that consists of selecting a subset of requirements or features to include in the next release of a software product, according to their expected revenues [11].

The goal is maximizing the total revenue without incurring in a total cost that exceeds the available budget.

At a lower level of abstraction, the NRP can be characterized as a specific variant of the 0/1 Knapsack Problem (0/1 KP), a classical NP-hard combinatorial optimization problem [12]. Equation 1 outlines the problem formulation, where decision variables $x_k \in \{0,1\}$ indicate whether the corresponding item is included (1) or not (0) in the knapsack. The knapsack capacity is analogous to the budget in the NRP formulation while items model the possible requirements to include in the next software release, each with an associated cost (i.e., the item's weight) and a given revenue (i.e., the item's profit).

$$argmax(\sum_{k=1}^{n} p_k x_k \mid \sum_{k=1}^{n} w_k x_k \leq C) \quad \text{[Eq. 1]}$$

In the case of the NRP, a dataset of instances solved by an exact algorithm is used to train VS. The training vector corresponding to one requirement includes the following features: the cost of the requirement, the revenue the requirement renders, and the total budget (which is fixed for all requirements in a given problem instance). The classification label is a binary value, indicating whether the requirement is to be included (1) or not (0) in the next software release, according to the reference algorithm. The VS implementation for solving the NRP used SVMs as supervised machine learning classifiers. The training set was built using problem instances solved by the Nemhauser-Ullmann algorithm, which computes exact solutions for the NRP [13,14].

Two different proposals were implemented for the improvement phase. The first scheme applies a simple local search heuristic to each generated solution, which performs random modifications to the candidate solution to exclude or include requirements. The second improvement scheme consists of correction and improvement operators inspired by a popular greedy strategy that selects requirements to include or exclude based on their revenue/cost ratio.

A thorough study of the training and prediction phases of VS was performed, and five different variants for the improvement phase of VS were analyzed for the problem. Experimental evaluation was performed using a publicly-available benchmark of problem instances of varying size and correlation between the revenue and the cost of the requirements, which is a measure of instance difficulty. The Nemhauser-Ullmann algorithm, an exact method for the problem, was used as the reference algorithm for VS.

Firstly, a brief comparison of different feature configurations was performed, which showed no significant differences among the considered options. Secondly, a study on the training set size—required for accurate learning—was carried out. Smaller subsets of 10%, 15%, 25%, 50%, and 100% of the observations in dataset #1 in the benchmark were considered. Results showed that a training set built using 15% of the dataset was enough to make accurate predictions. Beyond that percentage, only marginal improvements were observed. Thirdly, model parameters were configured using cross-validation.

When considering only the efficacy of the prediction phase on unseen instances, VS was able to predict the exact solution with a median accuracy larger than 90% when grouping instances by their size and larger than 80% when grouping instances by their revenue/cost correlation. Detailed results are presented in boxplots in Figure II which show the accuracy achieved when grouping instances by size and correlation, respectively.

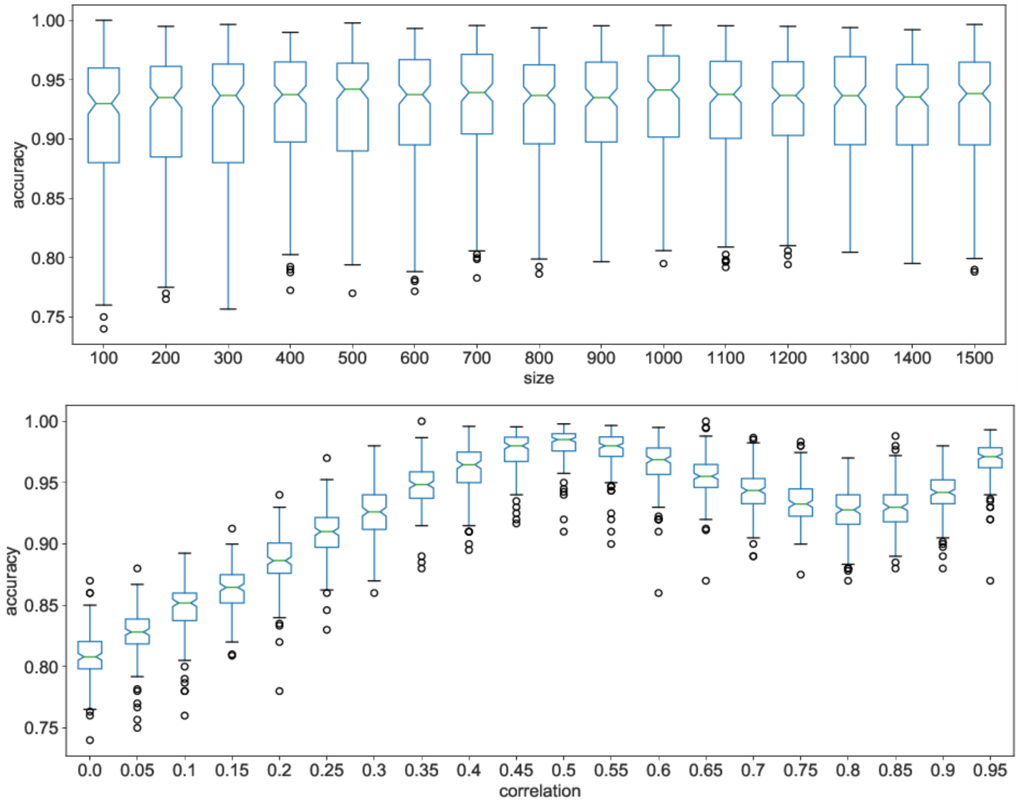

Figure II. SVM accuracy to predict the optimal solution with varying size/correlation.

The improvement phase in VS helps further refining the solutions generated in the prediction step. Experimental results showed that VS can compute highly-accurate solutions. Among the five improvement strategies devised, the simplest variant (a greedy mechanism that first corrects the solution and then improves it, based on the revenue/cost ratio of requirements) was the one that achieved the best results. The solutions computed by the VS version implementing this greedy mechanism were within 1% from the optima in all studied instances. Furthermore, VS was able to generate the optimal solution in many cases, and the computed solutions were within 0.2% (in median) of the known optima computed by the exact algorithm used as a reference. It was also observed that, interestingly, difficult instances for the reference algorithm were not necessarily difficult to solve for VS.

A detailed experimental evaluation of VS applied to the NRP can be found in [15].

3.2. Heterogeneous Computing Scheduling Problem. - The Heterogeneous Computing Scheduling Problem (HCSP) considers a heterogeneous computing system comprised of several resources (i.e., machines) and a set of tasks with variable computational requirements to be executed in the system. A task is defined as an atomic workload unit, i.e., it must be executed without interruptions and cannot be split into smaller chunks, which corresponds to a non-preemptive scheduling model. The execution time of any individual task varies from one machine to another and is assumed to be known beforehand, following a static scheduling approach. The HCSP proposes finding a task-to-machine assignment that optimizes some quality metric.

The scheduling problem addressed in this article focuses on optimizing the makespan, a well-known optimization criterion related to the productivity of a computing system. Makespan is defined as the time between the start of the first task (in the set of tasks to be executed) and the completion of the last task. Makespan is considered as a measure of productivity (i.e., throughput) of computing systems.

The mathematical formulation for the HCSP considers:

- A set of tasks $T = \{t_1, \dots, t_n\}$ to be scheduled and executed on the system.
- A set of heterogeneous machines $M = \{m_1, \dots, m_m\}$
- A function $ET : T \times M \to \mathbb{R}^+$ where $ET(t_i, m_j)$ indicates the execution time of task t_i on machine m_j.

The HCSP proposes finding an assignment function $f : T \to M$ that minimizes the makespan, defined by Equation 2.

$$makespan = \max_{m_j \in M} \left\{ \sum_{t_i \in T, f(t_i) = m_j} ET\left(t_i, m_j\right) \right\} \quad \text{[Eq. 2]}$$

The VS implementation for the HCSP uses a custom SVM framework (xphi-LIBSVM [16]) for learning. SVMs are trained using MinMin as the reference algorithm, which is one of the most widely used methods for solving the HCSP [17]. MinMin is a two-phase greedy scheduler that greedily picks the task that can be completed the soonest. Each task in the instance is considered individually during the training phase of VS. Therefore, each feature vector holds the execution time of one task on each machine and the classification label corresponds to the machine assigned to that task by the MinMin heuristic. Because tasks are independently assigned, VS can scale to problem instances with any number of tasks, without requiring any additional training process. A simple LS heuristic is applied over each candidate solution in VS, which iteratively moves a randomly-chosen task from the most loaded machine, i.e., the one with the highest completion time, to a machine selected among a subset of the least loaded ones.

The results computed by VS were compared to those computed by MinMin, the algorithm used by VS as a reference. Experimental results showed that VS outperformed MinMin in most of 180 problem instances, achieving up to 15% of improvement in terms of makespan. Detailed results are outlined in the boxplot in Figure III, which shows the ratio of makespan between VS and MinMin for different problem instances. Additionally, VS showed excellent scalability properties when increasing both the computational resources and the problem dimensions.

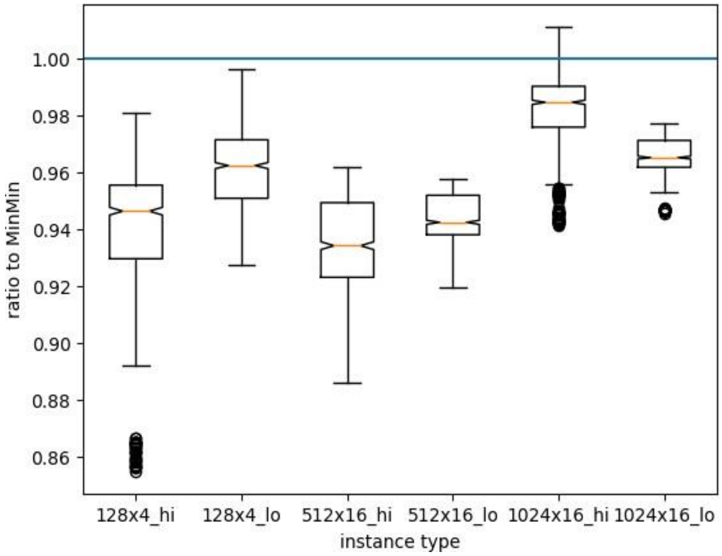

Figure III. Ratio of makespan: VS over MinMin for the HCSP.

Then, VS was evaluated on different computing platforms. Experimental evaluation over four different computing infrastructures showed that the massively-parallel design of VS allowed taking advantage of available computing resources to find accurate solutions for the HCSP. Increasing the number of parallel resources helped reducing the execution time of the prediction phase and did not increase the overall execution time, even though the computational demand of VS increases with the number of resources available. Besides, the makespan value (that evaluates the quality of the obtained results) generally decreased (i.e., improves) when increasing the number of threads.

Finally, VS was evaluated when solving very large problem instances—larger than those used during training—comprised of 32768 and 65536 tasks and 16 machines. Similar results to those obtained for the smaller instances were found, where the speedup increased with the number of cores, with a loss due to Hyper-Threading when the number of spawned threads exceeded the number of physical cores. However, speedup values were better for the largest instances studied. More details of VS applied to the HCSP can be found in [18].

3.3. Bus Synchronization Problem. - Public transportation planners often prefer network topologies comprised of few, short, and densely interconnected bus lines. This design is good from an operational point of view, because it allows operating higher bus frequencies with smaller vehicle fleets. However, it requires passengers to make more bus transfers instead of traveling directly from origin to destination. Passengers dislike transfers: studies have shown that the perceived time when waiting for a bus or when walking between bus stops can be up to 2.5 times larger than the real time spent [19]. Consequently, reducing waiting times for passengers when transferring between buses is a desirable goal from the point of view of citizens.

The Bus Synchronization Problem (BSP) consists in finding the headways of each bus line in a public transportation system, which allow maximizing the number of synchronized bus transfers.

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A bus transfer is considered synchronized when the waiting time experienced at the transfer bus stop does not exceed a given threshold, defined according to the maximum time passengers are willing to wait for the transfer.

The VS implementation for the BSP uses Random Forests (RF), which are trained using the solutions computed by an Evolutionary Algorithm (EA) used as a reference [20]. The best solution found on each independent execution of the reference EA over each training instance is used to build the dataset of solved BSP instances. Two different classifiers are trained: one to predict the headway of the inbound line and another one for the headway of the outbound line.

The improvement operator consists of a simple LS that selects a bus line in each step and randomly changes its assigned headway according to a uniform distribution in the range of valid headways for the line. The change is accepted if the quality of the solution improves and is discarded otherwise. The quality of the solution is measured through a score function, which reflects the problem formulation, and is used by the reference EA as a fitness function. The score function accounts for the number of synchronized transfers and their corresponding demands.

The experimental analysis was performed using two sets of problem instances: one comprised of 130 synthetic instances and the other of 45 realistic instances modeling the public transportation network in Montevideo, Uruguay. VS was able to compute accurate solutions in both sets of problem instances. In the synthetic dataset, VS computed solutions within 1.2% of the reference EA in median when only considering the prediction phase and within 0.2% in median when including a 5000-step LS improvement operator. In the realistic instances from Montevideo, VS computed solutions 99.5% as good as the reference EA in median when considering only the prediction phase and outperformed the EA in eleven out of fifteen problem instances when adding a 5000-step LS improvement operator.

The BSP allowed studying the applicability of the VS paradigm to a real-world optimization problem and evaluating its effectiveness with respect to baseline solutions. A more complex problem decomposition than those applied for the NRP and HCSP was needed to solve the BSP. The applied problem decomposition involved training two separate machine learning classifiers. Additionally, the implementation was done using RF---in contrast with the two previous applications of VS which used SVM---showing the versatility and adaptability of VS. The experimental evaluation was performed over larger instances (in terms of the number of bus lines and synchronization nodes) than those considered in the training phase. The experimental results highlight the scalability properties of VS in terms of the problem dimension, which were also noted in the other problems addressed in this article.

The complete application of VS for the BSP is reported in [21].

4. Conclusions and future work. - This article explored Virtual Savant, a paradigm inspired by the Savant Syndrome that combines machine learning and parallel computing to solve complex optimization problems. Implementations of VS were developed and evaluated for solving three optimization problems: i) the NRP, a well-known problem from software engineering that was modeled as a 0/1 KP; ii) the HCSP, a classic task scheduling problem relevant in modern computing infrastructures; and iii) the BSP, an optimization problem related to public transportation networks.

Due to its flexible design, VS can use different machine learning algorithms for the training and prediction phases. In the studied problems two different classifiers were used: SVMs for the NRP and HCSP; and RF for the BSP. Similarly, the design of VS is flexible in terms of the algorithm(s) used as a reference. On the studied problems, both exact and approximate algorithms were used as a reference.

The scalability of VS was evaluated both in terms of the problem dimension and in the use of computational resources. Regarding the problem dimension, VS was evaluated over problem instances much larger than those seen during training. This is a very interesting feature of the design of VS, since it allows solving problem instances that may not be tractable for the algorithm used as a reference. The scalability in the use of computational resources was evaluated on the HCSP. For this problem, four different computing platforms were considered, including shared- and distributed-memory architectures. Results showed that the massivelyparallel design of VS allows efficiently using available computing resources.

The work presented in this article was intended to be a step forward towards bringing closer the machine learning and optimization research fields, but many lines of work remain to be addressed.

Regarding the training and prediction phase of VS, other machine learning algorithms need to be considered. One promising line of work is to incorporate ensemble learning to VS. These classifiers could even be trained using different optimization algorithms as a reference or over different sets of solved instances.

Regarding the improvement phase of VS, other operators should be considered and evaluated. Tailored improvement operators that incorporate problem-specific techniques could be easily included in VS. Additionally, another interesting line of work would be to use the pool of candidate solutions generated in the prediction phase of VS to initialize a population-based metaheuristic, e.g., an EA.

Other optimization problems, potentially with harder constraints or dependencies between the problem variables, should also be considered. Furthermore, addressing multiobjective optimization problems is an interesting line of future work. For this purpose, a domain decomposition approach could be implemented, using a linear combination of the objective functions and training a set of classifiers with different weights.

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Impacto de los Vehículos Eléctricos sobre la Red de Distribución. Análisis bajo distintos modos de operación.

Impact of Electric Vehicles on the Distribution Network. Analysis under different modes of operation.

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Resumen. - La movilidad eléctrica es una alternativa sustentable que permite disminuir el consumo energético y la emisión de gases contaminantes con respecto a la movilidad convencional. Existen proyecciones que predicen un aumento del uso de vehículos eléctricos. Con esto se crean diversas líneas de estudio relacionadas a inferencias sobre las características de la integración de esta nueva demanda y sobre los efectos que generará en los sistemas eléctricos. Entonces, en el presente trabajo se proponen como principales objetivos: (i) determinar el impacto en la red de una inserción moderada de puntos de recarga públicos; (ii) evaluar el nivel de penetración de EVs de usuarios residenciales para modos de carga (G2V) domiciliaria lenta y semirrápida, según restricciones de variables de operación de la red; y (iii) proponer estrategias de gestión de la recarga controlada y la función dual de carga y aporte de energía a la red de los EVs a través de sus baterías de almacenamiento (V2G). Los resultados obtenidos muestran que la incorporación moderada de puntos de recarga públicos no afecta significativamente la operatividad de la red. Además, se muestra que la recarga controlada de los vehículos eléctricos logra disminuir los impactos negativos en el sistema eléctrico bajo estudio permitiendo mayores niveles de inserción y/o retrasando inversiones en infraestructura eléctrica. Un modo de operación con aporte de energía desde los vehículos eléctricos hacia la red permitiría desplazar generación de punta caracterizada por sus altos niveles de contaminación. Aun así, este modo de operación torna al sistema más susceptible a operar dentro de rangos inadmisibles.

Palabras clave: redes eléctricas, recarga controlada, restricciones, vehículos eléctricos

Summary. - Electric mobility is a sustainable alternative that allows the reduction of energy consumption and the emission of polluting gases with respect to conventional mobility. There are projections that predict an increase in the use of electric vehicles. Thus, several lines of research deal with the characteristics of the integration of these new demands and the effects that will occur on electrical systems. The main goals of this paper are: (i) to determine the impact of a moderate insertion of public charging points on the network; (ii) to evaluate the penetration level of EVs of residential users for slow and semi-fast home charging modes (G2V), according to restrictions of operation variables from the grid; and (iii) to propose some management strategies for controlled recharging and the dual function of charging and supplying energy from the electric vehicles to the grid through their storage batteries (V2G). The obtained results show that the moderate incorporation of public charging points does not significantly affect the operability of the network. Furthermore, it is shown that the controlled recharging of electric vehicles manages to reduce the negative impacts on the electrical system under study, allowing higher levels of insertion and/or delaying investments in the electrical infrastructure. An operation mode with energy from the electric vehicles to the grid would allow displacing the peak generation characterized by its high levels of pollution. Nevertheless, this mode of operation makes the system more susceptible to operating within inadmissible ranges.

Keywords: electrical systems, controlled recharging, restrictions, electric vehicles

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1. Introducción. - La definición de los objetivos de la agenda de desarrollo sostenible de la Organización de las Naciones Unidas [1], la creación del Acuerdo de París [2], la definición de políticas nacionales de cambio climático y acciones similares a nivel internacional, nacional o regional, demuestran el alto grado de importancia que adquiere actualmente disminuir o eliminar aquellas acciones perjudiciales para el medio ambiente. Según IRENA (*The International Renewable Energy Agency*) aproximadamente un tercio de la demanda actual de energía es atribuible al rubro del transporte, por su alta dependencia de combustibles fósiles [3]. Por esto, la movilidad eléctrica resulta ser una opción sustentable para mitigar la contaminación debida a la movilidad convencional. Además, permite integrar energías renovables en el rubro del transporte y disminuir su consumo energético.

La relación entre los sectores de transporte y energía eléctrica fue escasa hasta tiempos recientes. En términos generales, se observa que los vehículos eléctricos (EVs) traen consigo nuevos desafíos y posibles beneficios para las redes eléctricas [4]. La potencia eléctrica demandada o inyectada por los EVs resulta ser una variable crítica para el análisis del impacto en las variables de operación de las redes de distribución. Este tipo de análisis involucra una considerable cantidad de variables en juego. Al momento de efectuar estudios sobre la vinculación de los EVs con las redes eléctricas, resulta importante considerar el modo de operación de los EVs con respecto a las características de los flujos de potencia que pueden operar los EVs y sus cargadores en conjunto. El flujo de potencia admitido puede ser: (i) unidireccional, solo permitiendo una operación desde la red hacia el EV (G2V), o (ii) bidireccional permitiendo además una operación desde el vehículo hacia la red (V2G) [5]. En el mercado existe una variedad considerable de modelos de EVs y puntos de recarga. Además, cada región particular tendrá distintos hábitos de uso de la movilidad, afectándose las distancias diarias recorridas por los usuarios eléctricos, los lugares de recarga de EVs, el tipo de movilidad empleada y los tiempos de demanda de energía. Estos hábitos, terminarán definiendo los patrones de demanda de energía debida a los EVs de los habitantes de una región particular.

En el presente trabajo se plantean tres objetivos principales: (i) determinar el impacto en la red de una inserción moderada de puntos de recarga públicos; (ii) evaluar el nivel de penetración de EVs de usuarios residenciales para modos de carga (G2V) domiciliaria lenta y semirrápida, según restricciones de variables de operación de la red; y (iii) proponer estrategias de gestión de la recarga controlada y la función dual de carga y aporte de energía a la red de los EVs a través de sus baterías de almacenamiento (V2G). De esta manera se amplía el estudio realizado en [6].

2. Metodología. – En el presente trabajo, se adopta a la red de distribución eléctrica de la ciudad de Santo Tomé (Argentina) como unidad de estudio. Este sistema de distribución opera en el nivel de 13,2 kV y es abastecido mediante 3 estaciones transformadoras con niveles de tensión nominal de 132/34,5/13,8 kV. La red está conformada por 12 distribuidores eléctricos que alimentan a 233 subestaciones transformadoras (SETs), con niveles de tensión nominal de 13,2/0,4-0,231 kV. La red opera con una topología radial abasteciendo a 25.976 usuarios, de los cuales un 80,5 % son usuarios residenciales. En la Tabla I se presentan las denominaciones de los distribuidores, su potencia máxima operada y el número de usuarios residenciales abastecidos. La demanda para el escenario de pico es deducida mediante un análisis estadístico de los datos recolectados de las corrientes máximas diarias operadas.

Se modelaron perfiles semanales de demanda correspondientes a escenarios de invierno y de verano para cada distribuidor eléctrico, los cuales se determinaron mediante un análisis de registros reales de corrientes de cada distribuidor. Las simulaciones se realizaron con un software de simulación de flujos de potencia, donde se adoptó un paso de cálculo de 60 min. Para el análisis de los resultados se adoptaron como referencia los niveles de calidad del producto técnico exigidos en los procedimientos de CAMMESA [7]. Por otra parte, el nivel de cargabilidad admitido en los distribuidores se adoptó en función de la sección de los conductores, de su aislación y de factores relativos a sus condiciones particulares de montaje.

En las sub-secciones correspondientes al marco metodológico se detallan las consideraciones y criterios adoptadas para el estudio particular de la operación de la red con la inserción de EVs.

Denominación	$P_{máx}$ (MVA)	Usuarios Residenciales
Santo Tomé Sur	3,58	1855
Santo Tomé Norte	3,01	1451
Santo Tomé Centro	4,01	2553
San José	4,47	416

Loyola	2,83	2752
Lujan	5,28	3046
Mosconi	4,35	2623
Balcarce	3,93	2512
Saavedra	2,71	855
Roverano	2,42	909
Villa Adelina	1,90	1325
Villa Industrial	0,82	620

Tabla I. Denominación, Potencia Máxima y Número de Usuarios Residenciales de los distribuidores

2.1. Perfiles de recarga de EVs Residenciales. – Un perfil de recarga de un EV representa su demanda semanal de potencia. Cada SET tendrá asociada una determinada demanda debida a la recarga de los EVs de sus usuarios residenciales. Para determinar los perfiles de recarga de los EVs de cada SET se siguen los siguientes pasos:

- Determinar la cantidad de vehículos que componen la flota vehicular de la región en estudio.
- Modelar los ciclos de carga de las baterías de los EVs.
- Definir patrones de uso de los vehículos por parte de los usuarios residenciales.
- Obtener perfiles de demanda/aporte de potencia debida/o a los EVs para los usuarios residenciales.
- Obtener los perfiles de recarga de los EVs de cada SET.

A continuación, se describen los pasos mencionados. Para determinar la cantidad de vehículos que componen la flota en estudio, primero se obtiene la relación de automóviles por hogar en la provincia de Santa Fe a partir de información recolectada de informes de la Asociación de Fabricantes de Automotores [8] y del Instituto Nacional de Estadística y Censos [9], resultando ~ 1. Considerando a cada usuario residencial de la red en estudio como un hogar, se estima la cantidad de automóviles con motores de combustión interna que actualmente son utilizados en la ciudad de Santo Tomé, resultando un total de 20.197 unidades. Se conoce entonces la cantidad de vehículos asociados a cada distribuidor de 13,2 kV.

Los ciclos de carga de las baterías de los EVs se modelan según [10] y son transversales a las distintas etapas del estudio. Para su modelado se deben adoptar modos de carga/descarga y modelos de EVs a estudiar, porque cada EV posee distintos parámetros útiles para el modelado del ciclo de carga de su batería con cada modo de carga. Se consideran distintas tecnologías de sistemas de carga y modelos de EVs, según las tendencias actuales en regiones referentes de la movilidad eléctrica. En este estudio se adoptan tecnologías de recarga lenta y semi-rápida del tipo monofásicas y con potencias nominales de 3,5 kW y 7 kW, respectivamente. Los modelos de EVs adoptados son: Tesla Model 3 Standard Range Plus, Renault Zoe, Volkswagen ID3, Nissan Leaf y Hyundai Kona.

Se definen patrones de uso de los usuarios residenciales en base a posibles comportamientos reales: una distancia recorrida diaria intermedia de 20 km [11], un recorrido largo de 30 km, y un recorrido corto de 10 km. De esta manera, se definen para el estudio los usuarios con recorrido largo (URL), intermedio (URI) y corto (URC).

Para construir los perfiles semanales de recarga de EVs, se consideran: (i) los distintos patrones de uso, que permiten conocer el estado de carga de la batería cuando se conecta con la red y el momento en el que lo hace; y (ii) los ciclos de carga de las baterías; así se determina la curva de demanda de potencia al momento de requerir energía.

Los perfiles de carga debido a los EVs en cada SET se obtienen para escenarios de estudio, considerando distintos porcentajes de cada tipo de usuarios sobre el total de usuarios que poseen EVs, y distintos porcentajes de inserción de EVs en cada distribuidor con respecto al total de vehículos que componen el parque automotor.

2.2. Perfiles de carga de estaciones de carga semirrápida y rápida de 50 kW. – Un perfil de carga de una estación de recarga pública o un comercio se caracteriza por un mayor uso y potencia demandada con respecto a un punto de recarga residencial. En el presente estudio se analiza el impacto que genera la inserción de puntos de recarga en supermercados y estaciones de servicio de la ciudad de Santo Tomé.

En esta etapa se considera que las potencias máximas admitidas por los puntos de recarga de las estaciones de servicio son de 21 kW y 50 kW, y de los supermercados de 7 kW y 21 kW. La cantidad de puntos de recarga se distribuye equitativamente entre las alternativas de potencia máxima admitida propuestas. En los supermercados, se considera que aproximadamente el 20% de las plazas de estacionamiento poseen puntos de recarga semirrápida. En las estaciones de servicio se consideran instalados 4 puntos de recarga. Los perfiles de carga fueron adoptados bajo un enfoque pesimista. Según la potencia nominal de los puntos de recarga, se selecciona el modelo de EV que exija mayor potencia en función del tiempo. Se considera un porcentaje inicial de recarga de los EVs del 50% en supermercados y 10% en estaciones de servicio. Por último, se considera una dinámica semanal esperada de demanda para la recarga de los EVs en función del día de la semana y horarios de comercio. En la Figura I se presentan los perfiles generados de demanda de potencia semanal en los 4 establecimientos. Estas demandas de potencia afectan a las SETs encargadas de alimentar a cada uno de estos usuarios.

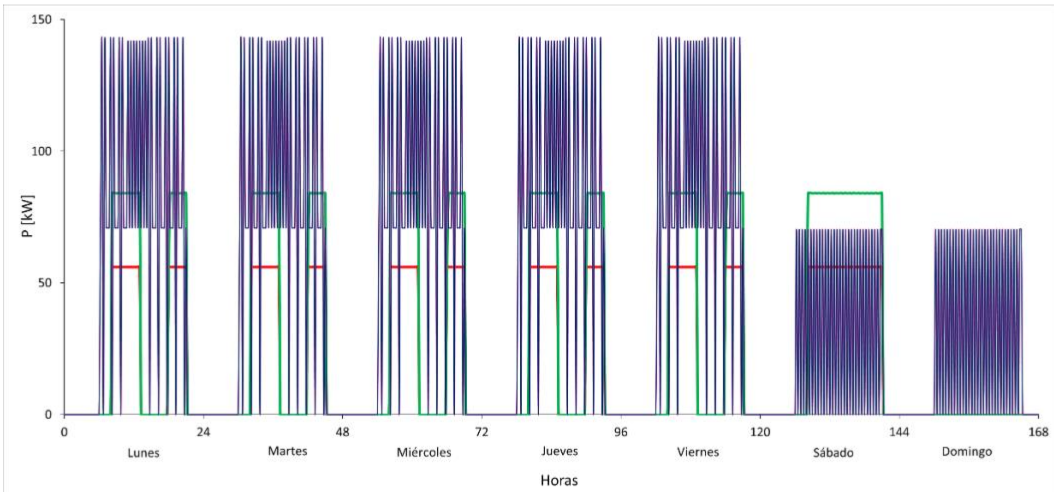

Figura I. Perfiles de carga semanal generados de los supermercados 1 (rojo) y 2 (verde) y de las estaciones de servicio 1 (magenta) y 2 (azul).

2.3. Modo de operación G2V no controlada. – Se plantean 8 perfiles de carga distintos. Una mitad se corresponde con una recarga lenta de 3,5 kW de potencia nominal y la otra con una recarga semi-rápida de 7 kW de potencia nominal. A su vez, en cada una de ellas se definen 3 perfiles considerando que el 100% de los usuarios con EVs pertenecen a un grupo de usuarios según su recorrido; y además un perfil considerando que los usuarios con EVs se distribuyen equitativamente con respecto a su distancia recorrida diariamente. Así, resultan los 8 escenarios planteados en la Tabla II.

A su vez, se consideran distintos porcentajes de penetración de EVs en el parque automotor de la región en estudio. En cada escenario de penetración se determina la cantidad de EVs correspondientes a cada SET. Según la potencia nominal de recarga a analizar se determina la potencia nominal de recarga de EVs en cada SET. Esta potencia nominal afecta a los distintos perfiles de carga generados obteniendo así los niveles de potencia demandada para una semana típica de invierno y una de verano. Las demandas de potencia debida a los EVs son adicionadas a las demandas típicas de cada SET.

Escenario	P [kW]	% URL	% URI	% URC
1	**3,5**	100	-	-
2		-	100	-
3		-	-	100
4		33,33	33,33	33,33
5	**7**	100	-	-
6		-	100	-
7		-	-	100
8		33,33	33,33	33,33

Tabla II. Escenarios de estudio propuestos para el modo de operación G2V sin gestión de la recarga.

2.4. Modo de operación G2V controlada. – Se procurará mejorar las condiciones de operación de la red con escenarios de recarga no controlada. Para ello, se proponen perfiles de recarga controlados de EVs con el propósito de aplanar el pico incremental de demanda de la red; y se los ubica en períodos de valle del sistema. Además, se debe evitar que la recarga de la flota de EVs ocurra en una ventana temporal pequeña, para no inducir un nuevo pico de demanda máximo del sistema. Estos perfiles propuestos pretenden simular una recarga controlada de la flota de EVs mediante algún sistema de coordinación de los distintos usuarios de la red. Tal recarga controlada se realiza intentando cumplir con: escalonar suficientemente los inicios de recarga del total de usuarios, evitar rangos horarios de recarga pequeños, y respetar ventanas temporales aceptables entre un escalón de recarga y el siguiente.

2.5. Modo de operación V2G de los EVs. – Se consideran distintos escenarios de la flota de EVs operando en modo V2G, y se obtiene el porcentaje admisible de inserción de EVs para cada escenario. Inicialmente se obtiene la energía total almacenada, considerando las distancias diarias recorridas por los URIs, el consumo energético de los modelos de EVs adoptados y una profundidad de descarga de su batería del 70%. Luego, se generan los correspondientes perfiles de carga semanales. Para ello, se asume que el aporte de energía por parte de los EVs persigue cubrir el mayor pico de demanda del sistema. En este sentido, se plantean valores de potencia para realizar el aporte de energía a potencia constante: 7 kW, 3,5 kW, y la máxima potencia posible de ser entregada durante el período de pico hasta alcanzar la profundidad de descarga adoptada (70%).

2.6. Indicadores de evaluación del impacto los EVs en la red. –Se adoptan los siguientes indicadores para evaluar el comportamiento de la red: la cargabilidad en distribuidores de 13,2 kV, la tensión en nodos del sistema, el Factor de Carga (F_c) de los distribuidores y el Factor de Pico de los distribuidores (F_p). El F_c permite evaluar en términos energéticos el grado de aprovechamiento del distribuidor:

$$F_c = \frac{S_{prom}}{S_{máx}} \quad \text{[Ec. 1]}$$

donde S_{prom} es la potencia aparente promedio demandada y $S_{máx}$ es la potencia aparente máxima demandada. El F_p permite evaluar en términos de potencia la contribución de la carga de los EVs al pico de demanda de los distribuidores respecto al escenario base (sin inserción de EVs), se obtiene según:

$$F_p = \frac{S_{ce\_máx}}{S_{cb\_máx}} \quad \text{[Ec. 2]}$$

donde $S_{ce\_máx}$ es la potencia máxima demandada en el caso de estudio y $S_{cb\_máx}$ es la potencia máxima demandada en el caso base. Por último, para el análisis del modo de operación V2G de los EVs, se adiciona la potencia mínima operada por los distribuidores como indicador de estudio. Este invierte su signo de positivo a negativo al ir incrementando gradualmente el nivel de inserción de los EVs, dado que se genera una inversión de los flujos de potencia. De esta manera, se conoce el porcentaje de inserción de EVs para los distintos escenarios que produce este fenómeno. Esto ocurre cuando la energía de la flota de EVs cubre la potencia del pico de demanda en algún tramo de un distribuidor e inyecta energía al mismo.

3. Resultados y Discusión.

3.1. Impacto de estaciones de carga semirrápida y rápida de 50 kW. – Debido a la locación de las estaciones de servicio y supermercados consideradas, las demandas recaen sobre el distribuidor Santo Tomé Norte y Mosconi. Los resultados muestran que existen variaciones marginales de la cargabilidad del tramo principal de ambos distribuidores debido a la instalación de los puntos de recarga en estaciones de servicio y supermercados. Esto último puede observarse en la Figura II, donde se presentan las cargabilidades de ambos distribuidores para una semana típica de invierno. Un comportamiento similar se obtiene con un perfil de demanda de verano. Con respecto al F_c, se observa que varía únicamente en el caso de un perfil de demanda de invierno en el distribuidor Santo Tomé Norte, aun así, solo disminuye desde 0,70 en el caso de referencia a 0,68 considerando la inserción de los puntos de recarga semirrápidos y rápidos. Por otra parte, se obtuvieron aumentos de entre 1% y 4% del F_p en los casos de estudio. Estos valores representan incrementos marginales de la potencia pico demandada con respecto al caso base de estudio.

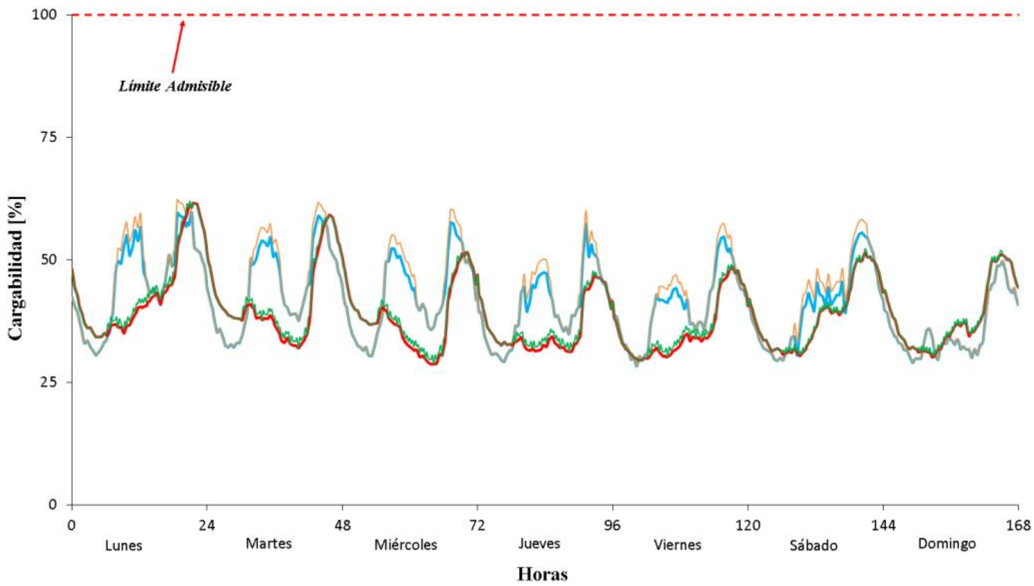

Figura II. Perfiles de cargabilidad semanal de distribuidores Santo Tomé (ST) Norte y Mosconi en caso base (celeste y rojo respectivamente) y con la instalación de puntos de carga semirrápida y rápida con un perfil de demanda de invierno (anaranjado y verde respectivamente).

3.2. Recarga EVs sin gestión de su demanda. – En la Figura III se presenta la variación de la cargabilidad en los distribuidores para distintos niveles de inserción de EVs y escenarios de estudio, considerando un perfil de demanda de invierno y verano. Con bajos niveles de inserción, la cargabilidad de los distribuidores es similar a la de su condición inicial (sin EVs). En términos generales, existe un aumento de cargabilidad proporcional al incremento de la inserción de EVs y se detectan mayores restricciones a la inserción de EVs con un perfil de demanda de invierno. Luego, según el caso de estudio, puede existir un mayor o menor aumento de la cargabilidad de cada distribuidor con un similar nivel de inserción de EVs. Se observa que existen distribuidores que admitirían el reemplazo completo del parque automotor convencional por EVs. Por otro lado, existe un distribuidor que en ningún caso de estudio admite este reemplazo completo y distribuidores que, dependiendo del caso de análisis, admiten o no este reemplazo. Aquellos distribuidores con mayor cantidad de usuarios residenciales poseen mayores aumentos de demanda por EVs. En este aspecto, la cargabilidad inicial puede ser determinante para el nivel de porcentaje admisible de inserción de EVs. En todos los casos, las restricciones de operación de la red se deben a sobrecargas en los conductores, y no se advierten restricciones debidas a valores inadmisibles de tensión en nodos.

El caso más exigente en cada distribuidor se presenta para los casos de estudio con URL y potencias de recarga de 7 kW. Esto es razonable por ser la mayor potencia de recarga y los URL deben recargar más energía diariamente. Entonces, la recarga de EVs es más prolongada en comparación con URIs y URCs, resultando mayor superposición de las demandas de potencia por parte de los usuarios residenciales.

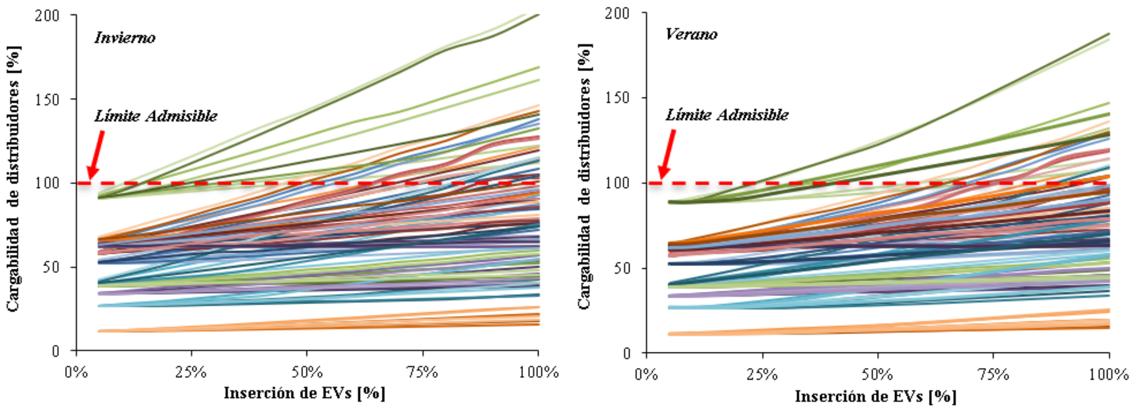

Figura III. Cargabilidad de distribuidores para según los casos de estudio propuestos sin gestión de la demanda.

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El porcentaje máximo admisible de inserción de EVs, para los perfiles de carga propuestos, sugiere que, en términos generales, las recargas con una potencia nominal de 3,5 kW presentan menores restricciones en comparación con las de 7 kW. Ningún caso de estudio admite el reemplazo completo del parque automotor convencional por otro de locomoción eléctrica, pues en todos los casos al menos un distribuidor presenta restricciones de inserción.

En la Tabla III se presentan los valores de F_c y F_p para el caso base y sus valores promediados para los casos con inserción de EVs con y sin gestión de la demanda. Se observa que F_c y F_p desmejoran notablemente ante una recarga no controlada de EVs, debido a importantes aportes al incremento de potencia pico de los distribuidores. Por otra parte, las recargas con potencias nominales de 3,5 kW presentan mejores condiciones de operación de la red que las de 7 kW. El análisis de los perfiles de cargabilidad de los distribuidores indica que, en aquellos distribuidores con una curva de demanda del tipo residencial, la recarga no controlada de los EVs coincide fuertemente en el pico diario de demanda. En la Figura IV se presentan las curvas de cargabilidad semanal para caso base y casos de estudio del distribuidor Luján considerando los máximos porcentajes admisibles de EVs de cada caso. Este distribuidor es el que más usuarios residenciales abastece. Se destaca el gran aumento de cargabilidad debido a la recarga de los EVs en los períodos de pico de demanda.

		Invierno		Verano	
Caso Base (Sin EVs)	F_c	0,69		0,68	
	F_p	1		1	
		Potencia nominal de recarga [kW]			
Con inserción de EVs		**3,5**	**7**	**3,5**	**7**
Sin gestión de la recarga	F_c	0,54	0,51	0,57	0,52
	F_p	1,44	1,56	1,36	1,53
Con gestión de la recarga	F_c	0,69	0,66	0,65	0,62
	F_p	1,08	0,15	1,18	1,23

Tabla III. F_c y F_p promedios sin gestión de recarga

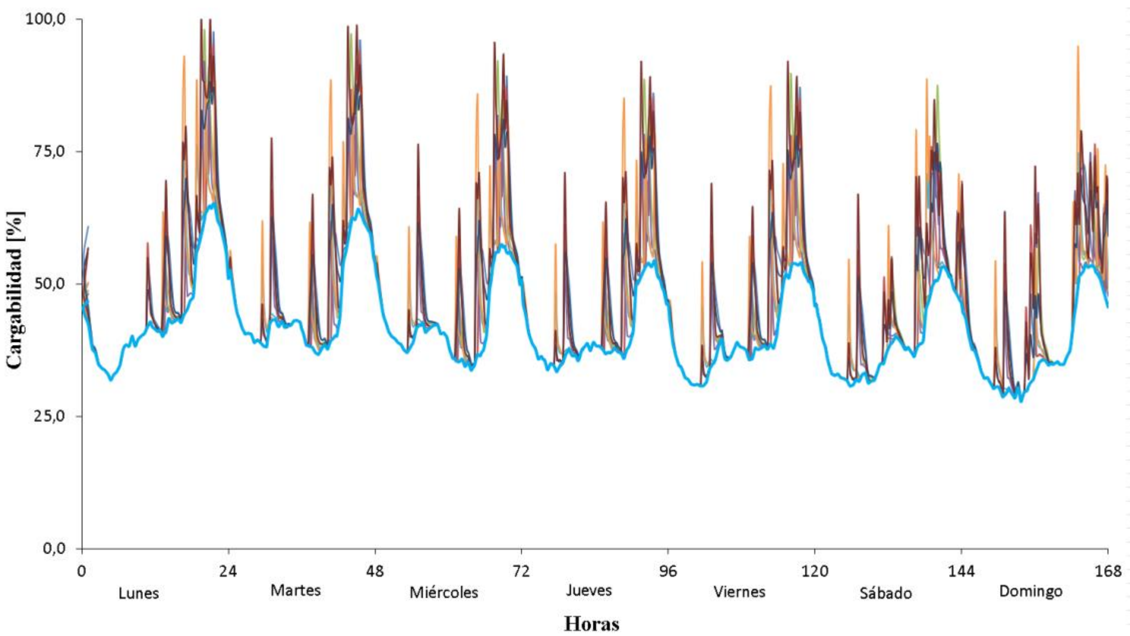

Figura IV. Curvas de cargabilidad semanal para caso base (línea celeste) y casos de estudio sin gestión de la demanda de los EVs del distribuidor Lujan (líneas de colores diferentes al celeste).

3.2 Recarga de EVs con gestión de su demanda. – Los distintos perfiles de recarga adoptados mejoran las condiciones de operación de la red con respecto a una recarga no controlada. Se obtienen resultados satisfactorios adoptando 8 escalones de recarga (cada octavo del total de los usuarios inicia su recarga en un horario distinto), ubicando el inicio de las recargas en períodos de valle de demanda y espaciando los escalones de recarga con período mínimo de una hora. Los resultados de las simulaciones sugieren que, con una correcta gestión de la recarga, los niveles de cargabilidad máxima de los distribuidores pueden disminuir considerablemente, mejorando así las condiciones de operación de la red y permitiendo un mayor porcentaje admisible de inserción de EVs en el sistema y/o un retraso de inversión en obras de infraestructura eléctrica. Se observa que no existe un número de escalonamientos, de rangos horarios de recarga, o de tiempo entre escalones de recarga, que satisfaga a todos los distribuidores por igual. Mediante un estudio particularizado a cada distribuidor es posible obtener mejores resultados. En la Tabla III se presentan los valores de los F_c y F_p promedios de los distribuidores considerando una gestión de la recarga de los EVs. Se observa una notable mejora de los F_c y F_p con respecto a una recarga no controlada. En la Figura V se presenta la cargabilidad semanal del distribuidor Lujan para el caso base y casos de gestión de la demanda para un perfil de demanda de invierno. Se destaca cómo se logra desplazar la demanda asociada a la recarga de EVs hacia los períodos de valle. Además, contrastando las Figura 4 y 5, se dilucida la disminución de la cargabilidad lograda mediante una adecuada gestión de la recarga de EVs.

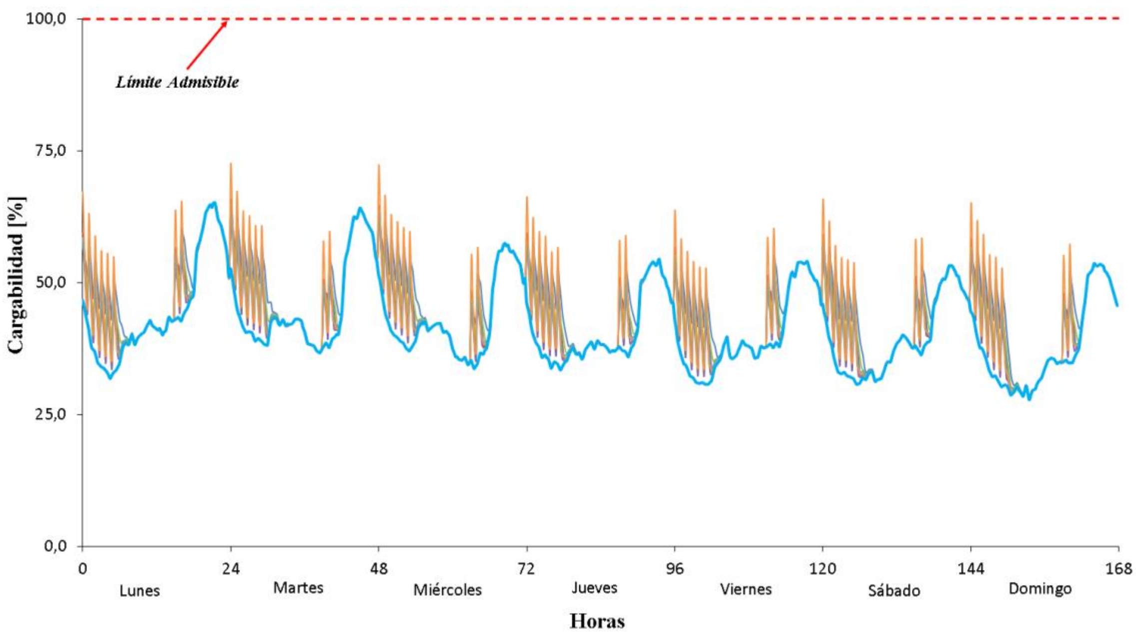

Figura V. Curvas de cargabilidad semanal del distribuidor Lujan para caso base (línea celeste) y propuestas de gestión de la recarga de EVs del distribuidor Lujan considerando un perfil de demanda de invierno (línea naranja).

3.3 Modo de operación V2G de los EVs. – Los perfiles de carga semanales (de invierno y verano) generados de los EVs con un comportamiento en modo V2G, permite dilucidar los importantes tiempos de recarga de los EVs posteriormente a haber entregado energía durante el período de pico de demanda. El porcentaje inicial de la recarga de los EVs es menor a los casos sin considerar aporte de energía a la red, por esto se requiere un mayor tiempo de recarga. La demanda de potencia más prolongada por parte de los EVs genera una superposición de los escalones de recarga propuestos en la recarga controlada de EVs.

En la Figura VI se presenta la cargabilidad máxima de los distribuidores. A diferencia de la Figura III, aquí se consideran únicamente URIs, pues se incorpora otra variable a considerar, las potencias de entrega de energía a la red, entonces con las posibilidades consideradas, se debería triplicar la cantidad de curvas presentadas en la Figura III, dificultando la interpretación los resultados. En algunos casos, se observa inicialmente una disminución conforme se aumenta el porcentaje de inserción de EVs, esto último se presenta principalmente en perfiles de demanda de invierno. Esta disminución de cargabilidades logra un valor mínimo para algún nivel de inserción de EVs y luego crece conforme se incrementa el porcentaje de EVs en el sistema. Por otra parte, existen distribuidores cuyos niveles de cargabilidad se incrementan para todo valor de inserción de EVs analizado. Estos comportamientos se deben a un nuevo pico de demanda en horas de la madrugada por causa de la recarga posterior de los EVs. En la Figura VII se presenta la curva de cargabilidad del distribuidor Lujan para los distintos casos con una inserción del 20% de EVs con este modo de operación. En la Figura VII, en el caso de entrega de potencia con 3,5 kW, no supera la cargabilidad máxima correspondiente al caso base. Por otra parte, los dos casos restantes del modo de operación V2G superan la cargabilidad del caso base. Si la cargabilidad máxima del distribuidor debida al nuevo pico de demanda es mayor a la obtenida sin considerar el aporte de energía por parte de los EVs, entonces no se justifica el modo de operación V2G. Por esto, se considera que los distribuidores que no presentan una disminución de cargabilidad inicial, no admiten ningún porcentaje de inserción de EVs. La mayor admisión de EVs con este modo de operación se presenta con un perfil de demanda de invierno y con entregas de 3,5 kW.

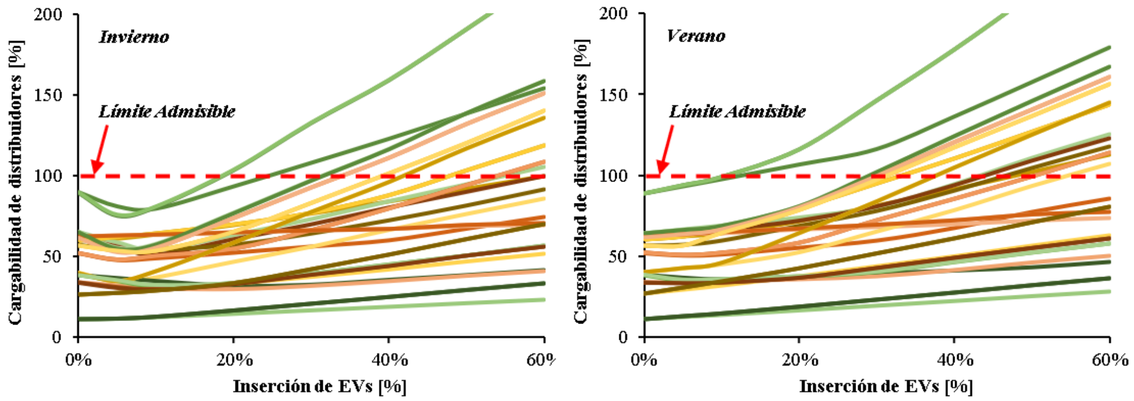

Figura VI. Cargabilidad de distribuidores para los distintos casos de estudio con modo de operación V2G de los EVs.

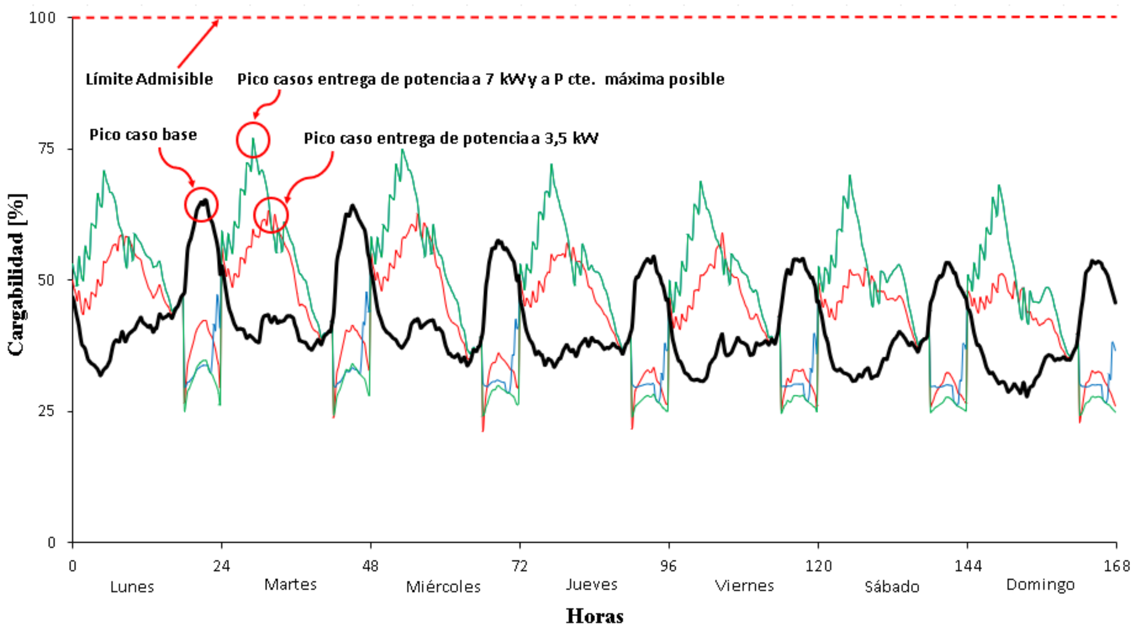

Figura VII. Perfiles de cargabilidad del distribuidor Lujan en caso base (negro) y casos de estudio de inserción de potencia con 3,5 kW(rojo), 7 kW(azul) y a la Potencia máxima constante posible (verde) con un nivel de inserción de 20% y considerando perfil de demanda de invierno.

En la Figura VIII, se presentan los niveles de potencia mínima operada por el tramo principal de los distribuidores de 13,2 kV para los distintos casos de estudio según distintos niveles de inserción de EVs operando en modo V2G. En términos generales, se observa que hasta una inserción del 5% de EVs, ningún distribuidor presenta inversión de flujos de potencia. Por otro lado, solo uno de los doce distribuidores no presenta una inversión de los flujos de potencia para los porcentajes de inserción de EVs analizados, caracterizándose el mismo por poseer el menor número de usuarios residenciales abastecidos. Estos resultados se verifican para ambos perfiles de demanda. Las Figuras VI y VIII muestran que el perfil de demanda de verano es mas restrictivo con respecto a la inserción de EVs cuando operan en modo V2G. Ocurre lo contrario para los casos de estudio sin considerar el modo de operación V2G.

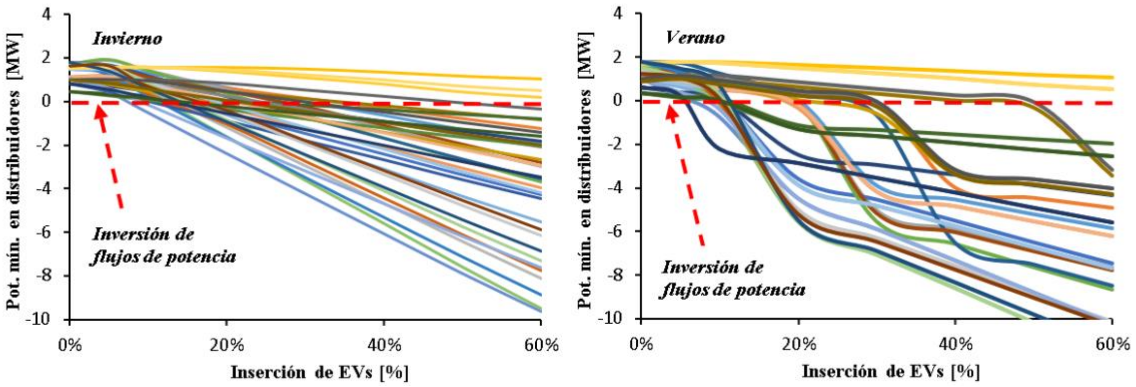

Figura VII. Potencia mínima operada por los distribuidores de 13,2 kV según distintos casos de estudio para diferentes niveles de inserción de EVs operando en modo V2G.

En términos generales, cuando los EVs adoptan un comportamiento como el propuesto, se encuentran mejores condiciones de operación del sistema para aportes de 3,5 kW. Con esta potencia, los EVs no logran alcanzar la profundidad de descarga propuesta en el análisis y demandan menos energía luego de abastecer a la red eléctrica. De esta manera, es posible admitir una mayor cantidad de usuarios con sus EVs operando en modo V2G. Existen distribuidores que no admiten este modo de operación y otros que admiten niveles de inserción de entre 5% y 50%. Los niveles admisibles de inserción de EVs con este modo de operación son notablemente menores que los correspondientes al caso de estudio de inserción de EVs sin gestión de la recarga. En las secciones analizadas se consideraron al total de los EVs en el sistema con un tipo de comportamiento específico (y a su vez con distintos perfiles de uso), es decir todos sin gestión de la recarga, con gestión de la recarga o con modo de operación V2G. Es dable destacar que en este trabajo no se consideró una combinación entre los distintos tipos de comportamiento de los EVs.

4. Conclusiones. – El presente trabajo sugiere que los puntos de recarga semirrápida y rápida en supermercados y estaciones de servicio, en general, no ocasionan importantes desmejoras en los parámetros de operación de los distribuidores analizados. Por otra parte, se comprobó que una gestión de la recarga de los EVs permite disminuir los impactos negativos sobre la red, posibilitando niveles de inserción superiores y/o retrasando inversiones en infraestructura eléctrica. Además, se determinó que el sistema en análisis admite un determinado porcentaje de inserción de EVs con un modo de operación V2G que permitiría desplazar generación de punta altamente contaminante mediante el aporte de energía por parte de los EVs en los períodos de pico de demanda del sistema. Aun así, con este modo de operación, el sistema es más susceptible a operar fuera de los rangos admisibles determinados para el estudio, pues con un menor porcentaje de inserción que otros casos se violan restricciones operativas. El trabajo además muestra la existencia de numerosos posibles escenarios de utilización de los EVs en las redes eléctricas y sus parámetros más influyentes. Se observa la elevada incidencia del modo de uso de los EVs, resultando de interés evaluar además casos de posibles flexibilidades por parte de los usuarios, pudiendo estos optar por una recarga no controlada o controlada, y en este último caso, con o sin aporte de energía a la red.

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