VEHICLE ROUTING OPTIMIZATION INSIGHTS: INNOVATION, IMPLEMENTATION AND RESEARCH COLLABORATION OPPORTUNITIES

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ABSTRACT

Vehicle Routing Optimization (VPO) plays a key role in the operations of a company, leading to a more efficient way to deliver and/or collect its products from its depots to its customers. As technology grows, VPO becomes more feasible and in the future this kind of quantitative methods may become part of generic technologies for logistics and everyday life. However, a successful link must be stablished between those who are researching in theories and those who are applying them, developing new technologies and making innovation. This paper explores global trends on scientific and technologic production that apply VPO techniques through a patent analysis and a bibliometric analysis that is a review of the lifecycle, scientific and technologic impact, leading countries and the identifications of trends in order to find knowledge gaps and opportunities in research, implementation and collaboration.

Key words: Vehicle Routing Problem, VRP, Bibliometrics, Patent analysis, Vehicle Routing Optimization, VPO.

INTRODUCTION

The distribution of goods is important due to the percentage of the costs that it represents for any company. It amounts to about 20% of the total cost of an average product (Reimann, Doerner, & Hartl, 2004) and this is happens due to the transportation occurring within members of a supply chain and from the chain to the final customer. Thus, transportation becomes an area in which many instances can be optimized.

The Vehicle Routing Problem (VRP) works as a tool for logistics and can be defined as a type of mathematical problem that can be solved by quantitative models for optimizing delivery or collection routes from one or several *depots* to a set of geographically scattered *customers* or *cities*, subject to constraints (Laporte, 1992). It was proposed by Dantzig & Ramser (1959) as a generalization of the truck dispatching problem and introduced in the logistics and transport field by Clarke and Wright as a detailed linear optimization problem (1964). As shown in Figure 1, each black numbered dot is a node and represents a client, each line between nodes is an edge, which has direction and represents a part of a given route and the special node D is a depot.

Classic VRP assumes that every route starts and end at the depot, each customer is visited exactly once, the total demand corresponds to the sum each route's demand and that the total cost is minimized (J-F Cordeau, Gendreau, Laporte, Potvin, & Semet, 2002). However, there exists all kind of variations that fit in a great variety of contexts changing the nature of the objective function that determines what is going to be minimized as cost, distance travelled, CO_2, etc. or maximized as profits or utilities. One could also change the nature of the restrictions and even the computational method that is used to solve the VRP.

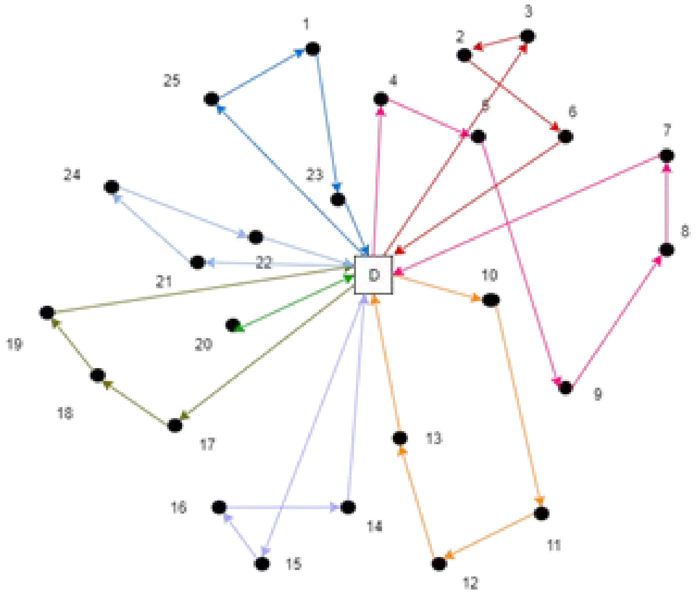

Figure 1: General graphical representation of a VR Network, Source: own elaboration on draw.io

As complexity increases with each node and constraint added to the problem, the amount processing speed and memory available required grows too, in an exponential way (Braekers, Ramaekers, & Van Nieuwenhuyse, 2016). This encourage researchers to develop better algorithms and solve larger instances of VRP (Eksioglu, Vural, & Reisman, 2009). In turn, the creation of VRP solving solutions is stimulated, and they are acquired by companies of all sizes and industry sectors.

Despite the growth of publications on VRP, the assessment of the research and inventive productivity in a quantitatively and systematic way is not found in the literature. Thus, an analysis of the main trends that are being developed in terms of theories and applications with scientific production and technologies with inventive production would help to identify opportunities for innovation, scientific research and collaboration.

Bibliometrics analysis is an statistical analysis for evaluating research outputs, importance, influence of authors, institutions, etc. (Geng et al., 2017) in published units of literature as they are reflected in bibliographies (Hood & Wilson, 2001). For patent analysis, patent citation analysis has been the most frequently adopted tool (Lee & Park, 2009) and statistics search for industrial impact of companies and institutions and patent trends that, from the perspective of technology management planning, will help to identify the dynamics of competitors and reviewing whether or not to introduce new technologies (Kim & Bae, 2016). Though not all inventions are patentable since they may not meet patentability criteria (Ardito, D 'adda, & Petruzzelli, 2017), this hole can be filled partially with the inquiry of scientific production.

In order to present and analyse statistical data concerning the VRP through time and to identify potential future trends for collaborative research and innovation, this paper is organized as follows: section 2 introduces the methodology followed for the bibliometric analysis, section 3 corresponds to the explanation and analysis of the figures and tables that were generated and section 4 presents the conclusions of the literature review.

METHOD

With the objective of getting the required information for the analysis of VRP insights, a list of methodological steps was set that combines some strong points of bibliometric analysis and patent analysis. While basic statistics allow to create descriptive graphics, it is also important to assess the discipline's evolution in a qualitative manner. Several relational techniques can help in reducing the subjectivity of assumptions; moreover, it is also helpful to examine weaknesses and strengths, to signal research gaps and to identify future research directions in a certain area (Geng et al., 2017)

To identify the tendencies in VRP, the following methodology is presented:

i. Planning of the searching strategy: a subject or area of knowledge is selected to be studied to asses if it is relevant for the academic or productive sector. A query string is designed to set boundaries in the research to avoid analysing data that is not related to the subject. This step may require the opinion of experts and concertation. Then, the database is also selected taking into account the reliability and fitness for the subject explored and the type of analysis that is going to be made.

ii. Download and processing of the scientific activity and patenting innovation activity: using the query string, the information needed for the study will be downloaded from the databases selected and its suitability is assessed one more time.

iii. Developing the bibliometric analysis: the analysis is made through indicators that are chosen by the researcher to better describe the data that is obtained from the database selected and that is relevant to the subject. This phase will include the creation of indicators by statistical methods and a citation analysis.

iv. Consolidation of a summary of the subject insights: the most important branches that are currently being worked upon are selected and briefly described, a sampling method is used for both bibliometrics and patents analysis.

FINDINGS

Databases and query string

An expert in operational research was consulted to determine the keywords which would help find any document related to the vehicle routing problem and to eliminate or exclude any term that would introduce a deviation that would affect the data collection process. The resulting for the query strings is shown in Table 1. The query string contains the conditional operators AND, OR, NOT because VRP is an acrostic and it may have different meanings in not-related fields. Ex: virus replicon particles (VRP). These unrelated terms were found by testing the query string and were excluded manually.

The selected database for bibliometric analysis was SCOPUS. As the official page of Elsevier (2017) states: “Scopus is the largest abstract and citation database of peer-reviewed literature: scientific journals, books and conference proceedings. Delivering a comprehensive overview of the world's research output in the fields of science, technology, medicine, social sciences, and arts and humanities, Scopus features smart tools to track, analyse and visualize research.” Its effectiveness and the possibility of easily exporting publication metadata makes SCOPUS an appropriate tool for use in statistics based bibliometric analysis.

As for the patent analysis, Web of Science (formerly ISI, Web of Knowledge) database was used specifically the Derwent Innovations Index. According to Clarivate Analytics (2017): “By meticulously indexing the most important literature in the world, Web of Science has become the gold standard for research discovery and analytics. Web of Science connects publications and researchers through citations and controlled indexing in curated databases spanning every discipline.” These databases fulfil the purpose of the research and they are not equal due to the specialization of each one that helps doing a deeper analysis in each aspect.

Table 1: Description of the query string for a search on Vehicle Routing Problem, Source: own elaboration

Subject	Vehicle Routing Problem	
Expert’s name	Msc. Luis Othon Gómez Rueda	
Analysis	Bibliometric analysis	Patents analysis
Query string	TITLE-ABS-KEY ("vehicle routing problem" OR "VRP" OR "routing optimization" OR "vehicle routing optimization")	TS = (VEHICLE* AND ROUTING*) NOT TS=(MATERIAL* OR BROADCAST* OR

	AND SUBJAREA ("ENGI" OR "MATH" OR "BUSI" OR "DECI" OR "COMP") AND DOCTYPE ("ar" OR "cp" OR "ch" OR "ip" OR "bk") AND NOT (TITLE-ABS-KEY ("vertebral" OR "veteran" OR "tumor" OR "voice range profile" OR "verapamil" OR "virus replicon particles" OR "variance risk premium" OR "ventilation rate procedure" OR "vapor recondensation process" OR "electronic coupling constant" OR "Variational Riemann Problem"))	TELECOMMUNICATION* OR OPTICAL* OR TELEPHONE* OR ROBOT* OR PAYMENT* OR SEMICONDUCTOR* OR PARKING* OR CELLULAR* OR HYDRAULIC* OR HARNESS*)
Database	SCOPUS	Web of Science
Date of the inquiry	13/06/2017	02/08/2017
No. of Documents found	6123	2779

General Analysis

Lifecycle

The number of documents related to Vehicle Routing Problem began to rise slowly during the first decade of study (70’s & 80’s) in the US under the influence of Dantzing and Ramser, who introduced the “Truck Dispatching Problem” in 1959, and the key work of Clarke and Wright who detailed the first linear optimization problem for logistics and transport in 1964. As computational processing capacity increases and the cost of this capacity decreases, the number of documents has grown considerably while incorporating an ever-increasing amount of real-life complexity elements (Braekers et al., 2016).

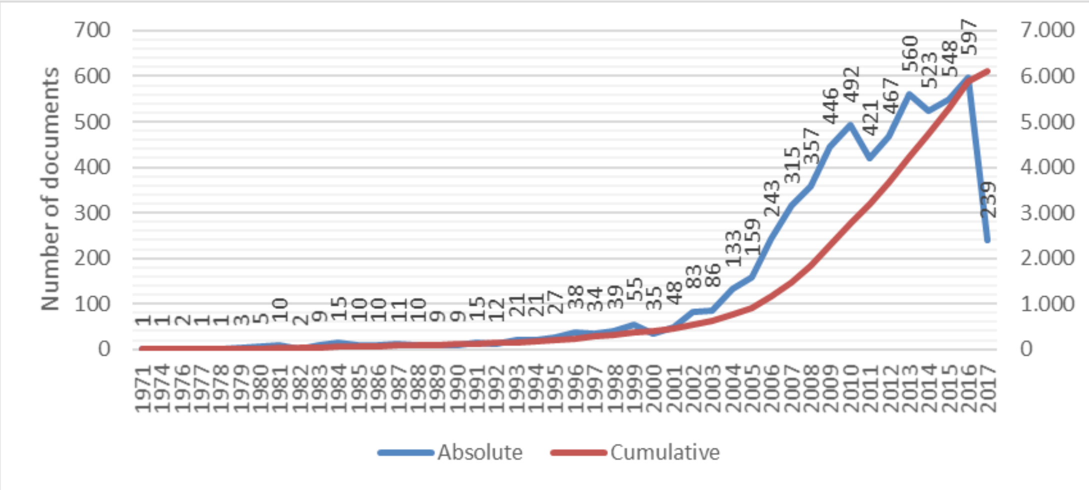

Figure 2: Lifecycle for scientific production related to Vehicle Routing Problem (1971-2017), Source: own elaboration from SCOPUS data

By 2002, a Notebook PC superseded the computing power of the first “supercomputer” Cray-1, built by Seymour Cary in 1976. In the history of computing it is also important to recall the big changes that occurred in the first half of the 90’s where the whole architecture of computing systems changed (Oyanagi, 2002).

This relationship is based on the computing capacity required to solve VRP optimization models. It is a fact that exact algorithms are only efficient for small problems instances and that heuristics allow to simulate more realistic situations of big enterprises with large fleets and thousands of customers or companies whose products require special handling. As complexity increases with each node and constraint added to the problem, the amount processing speed and memory available capacity grows too, in an exponential way (Braekers et al., 2016). This helps researchers to develop better algorithms and solve larger instances of VRP (Eksioglu et al., 2009), stimulating the creation of VRP solving software, which is in turn is acquired by companies of all sizes and industry sectors.

As shown in Figure 2, although 2011 & 2014 show a slight decrease in the number of published documents, an increasing pattern is evident. Thus, it can be stated that scientific activity is in the growing stage, and it can be inferred that the Vehicle Routing Problem is indeed a global tendency that will continue to grow in the future as computing technology becomes more advanced.

Regarding inventive activity in Figure 3, it starts in the 90’s and the first inventions are related to digital computers, servers and equipment specially arranged with methodologies for the measure and/or prediction of data regarding vehicles and networks of vehicles as traffic status -average speed, problems in the roads, etc. GPS is already on use so technologies of real time recollection and analysing of data were create. And simple routing optimization methods were implemented in some vehicles through appliances to give real-time indications of the deliver or recollection points and routes already calculated.

In the 2000's, technologies for planes and commercial automobiles are developed, just to name some advances. And for the technologies of the 2010's more complexity is added to the calculation, new and more interconnection systems, data transfer and decision making in real time with high efficient and fast computing equipment.

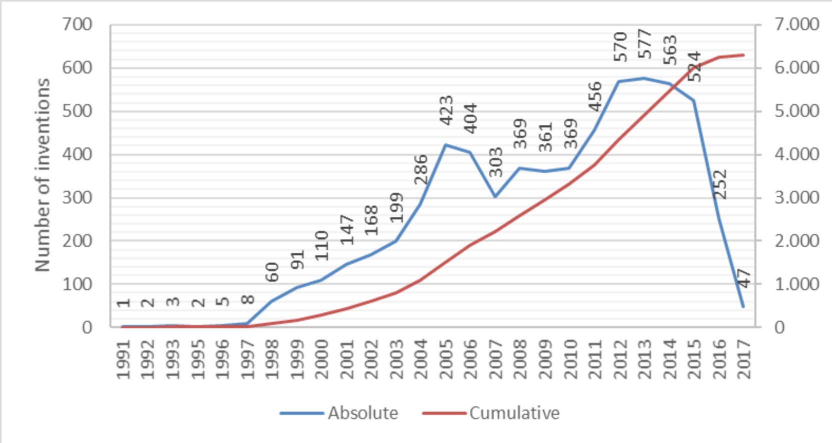

Figure 3: Lifecycle for inventive activity related to Vehicle Routing Problem (1991-2017), Source: own elaboration from Web of Science data

Lifecycle line in Figure 3 shows an increasing trend similar to the scientific production one. There is a little valley in 2007 but it recovers and it can be said that inventive activity finishing the growing stage and starting its maturity stage. Nevertheless, it may be soon to give a final word because the patent that appears in Web of Science database are patents already approved, this means that there is no information of the patents that are under revision. In average, only 6% of the patents were approved the same year and 30% on the following year. So, as for the last years, an incomplete scenario is being showed.

Leading countries

China is the leading country by far, with 3185 publications related to VRP (see Figure 4). The second place is claimed by the US –where VRP was born– with 1168. Next follows France with 552 documents, almost half of the previous country's contributions. Afterwards, the number decreases slowly with Canada (541), Spain (356), Italy (323), Brazil (302), Germany (294), United Kingdom (290) and Japan (280) completing the top 10. The first Latin American country to show up is Colombia, in the 25th position. 61 countries make up the rest of the list, and contribute with 1258 additional articles.

The importance of VRP research in China is tied to its context: today, investments in the Asian country are focused on industry and logistics, but go beyond handling, transportation and storage of goods. Logistic services are required to provide intelligent solutions for the entire Supply Chain. Saving resources is not the only priority, reliability (being on time and delivering goods in optimal conditions) has turned too into a key concern. This has resulted in new challenges and measures such as the one undertaken in 2010: upgrading 3.583.715 kilometres of roads (PricewaterhouseCoopers, 2012).

Many Chinese enterprises are interested in routing optimization. A survey performed in 2012 to 250 Chinese enterprises of the PricewaterhouseCoopers (PwC) network shows that 20% of the surveyed companies plan on implementing optimization and 20% have already implemented it. The background to this decision has, too, an environmental background due to regulations implemented by the Chinese government.

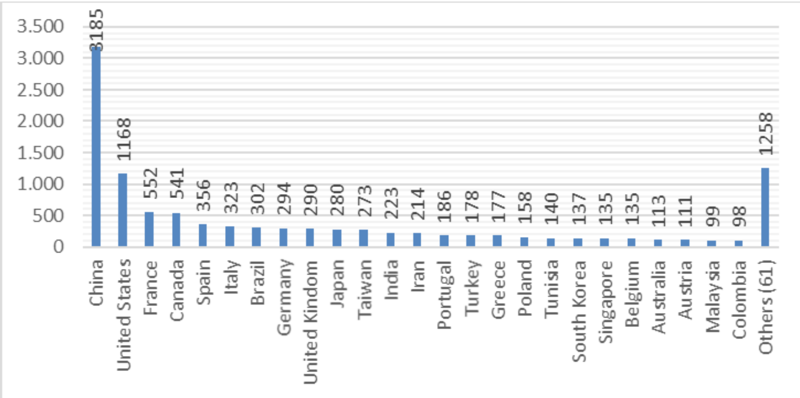

Figure 4: Leading countries in scientific production related to VRP (1971-2017), Source: own elaboration from SCOPUS data

Technology has created a breach between big, sometimes foreign companies, and small or medium-sized logistics service providers (SMLSPs). The latter have a lower rate of customer satisfaction. A solution that could improve their service quality is to enhance their technologies and related assets or to outsource logistics to external peers. All improvement should be done prioritizing short-term benefits such as costs, relative advantage, etc., and long-term benefits like efficiency and green-friendly policies have to be achieved through on-time delivery and vehicle routing, among others (Subramanian, Abdulrahman, & Zhou, 2015)

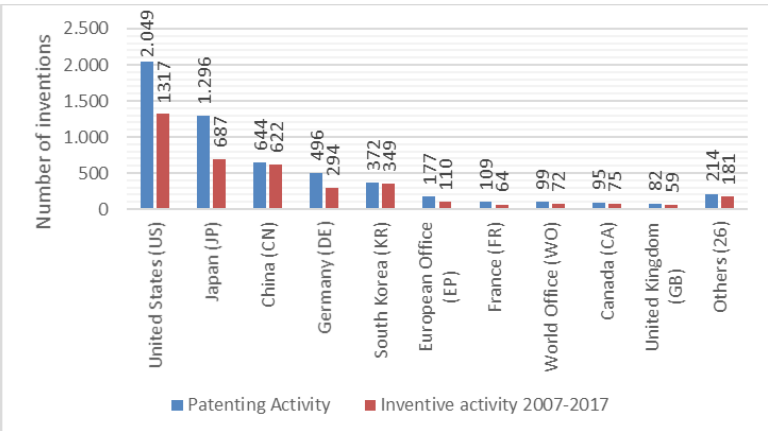

Figure 5: Leading countries in patenting activity related to VRP (1991-2017), Source: own elaboration from Web of Science data

In this manner, the role of VRP solutions becomes evident, as they are linked to finding the most cost-effective model for specific products using multi-modal transportation networks and reducing environmental impact to the minimum.

Given the size of these networks, computational processing and efficient algorithms are also part of the challenge and said goals are translated into future research work. Thus, a review of scientific production on VRP in China would be a relevant exercise.

There are notable differences between the leading countries on patenting technologies related to VRP, but information in Figure 5 can be used to make some relations. China (CN), occupies the third-place patenting activity and this confirms that though in the academic field VRP is being studied, there’s a lack of capacity to implement this new knowledge, resulting in the perpetuation of a chaotic scenario for inner logistics in China as described before.

Differences between these two indicators also show that there is a disconnection between the academic field and the technology development field. It is important however that integration occurs to a more efficient way for industrial innovation. Even proximity from firms to universities influences the quality of the academic research and the university-firm interaction in a positive way (Maietta, 2015).

In this case, the United States (US) leads the patenting activity with 2049 patents, more than half of them registered in the past ten years. The logistics scenario of this country is highly competitive. In fact, a growing number of US regions are pursuing specialization in transport and logistics due to the easy access to various forms of transport, cost effective transportation services and efficient logistics. This has allowed the US to achieve a comparative advantage to other regions (Kumar, Zhalnin, Kim, & Beaulieu, 2017).

The presence of Japan (JP) in the second place with 1296 and Germany (DE) in the fourth place with 496 patents gives a hint on how patenting activity of these technologies impacts on the competitiveness of the urban logistic services offered in these countries. Countries like China, South Korea (KR), Canada (CA) and United Kingdom (GB) are new players on patenting technologies related to VRP, their inventive activity in the last 10 years covers a high percentage of the overall activity so it can be said VRP technologies are new to these countries.

Scientific and industrial activity, impact and collaboration

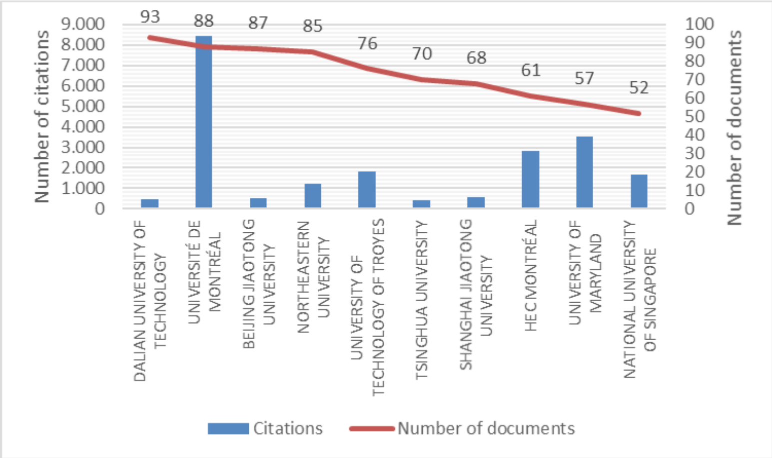

Figure 6: Top 10 Institutions by scientific activity (1971-2017), Source: own elaboration from SCOPUS data

A top 10 of scientific activity shown in Figure 6 is made counting the number of documents published by institution. China takes the lead again with Dalian University of Technology with 93 documents, the Université de Montréal from Canada is in second place with 88 documents. Then, in the following places are: Beijing Jiaotong University form China, Northeastern University from China, University of Technology of Troyes from France, Tsingua University from China, Shangai Jiaotong University from China, HEC Montréal from Canada, the University of Maryland from the US and the National University of Singapore from Singapore.

Though 5 Chinese institutions are in the top of scientific activity, their contributions have very few citations meaning that they are not as influential as other countries' institutions. As for the Dalian University of technology, their contributions only represent a 3% of Chinese academic production. In fact, if a reordering is made as in Figure 7, the real influence of the institutions can be assessed moving Université de Montréal to the first place with 8463 citations with its contributions representing a 16% of the national academic production, in second place the University of Maryland from the US with less than a half of the citations o the previous one (3511). While in China, scientific activity is spread, in influential countries like Canada is focused in a handful of institutions.

The other 8 institutions in the ranking by citations come as follows: University of Bologna from Italy, HEC Montreal form Canada, The "Centre de Recherche sur les Trasports" (CIRRELT) from Canada, the University of Troyes from France, the National University of Singapore from Singapore, the University of Vienna from Austria, the National Technical University of Athens from Greece and the University of Copenhagen from Denmark. For China, the most influential institution is the Northeastern University in 11th place.

These institutions can be used as global references and future research will likely have its foundations on their publications. Whether to trust or not scientific production in China is a concern that should be explored in a more specific study. If new researchers want to be recognized in the global academic field regarding

VRP findings then the journals shown in Figure 8 are recommended. All institutions of Figure 7 have published in at least three of these journals.

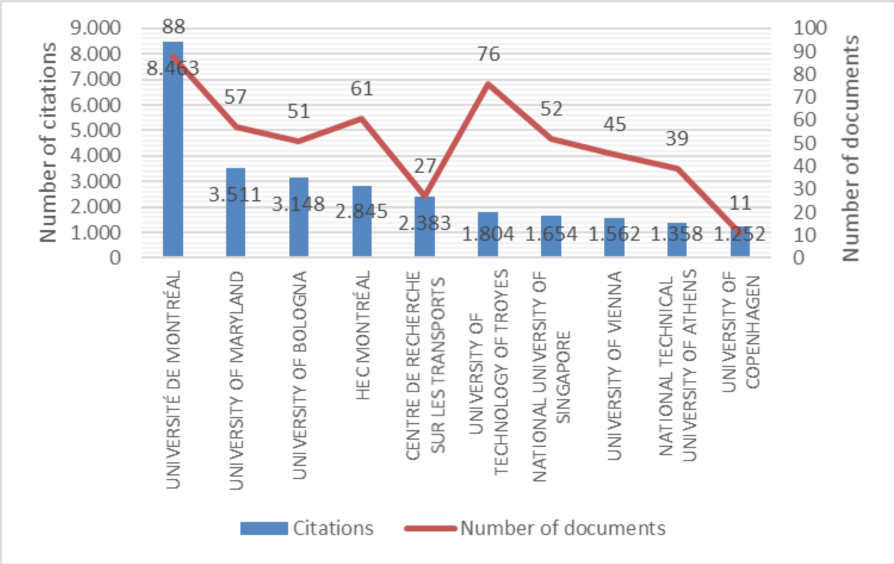

Figure 7: Top 10 Institutions by number of citations (1971-2017), Source: own elaboration from SCOPUS data

The journal in first place is the European Journal of Operational Research with 9914 citations from 228 documents, followed by Computers and Operations Research with 9859 citations from 203 documents. Then, Transportation Science, Operations Research, Networks, Journal of the Operational Research Society, Lecture Notes in Computer Science, Expert Systems with Applications, Annals of Operations Research, Annals of Operations Research, Computers and Industrial Engineering and Journal of Heuristics.

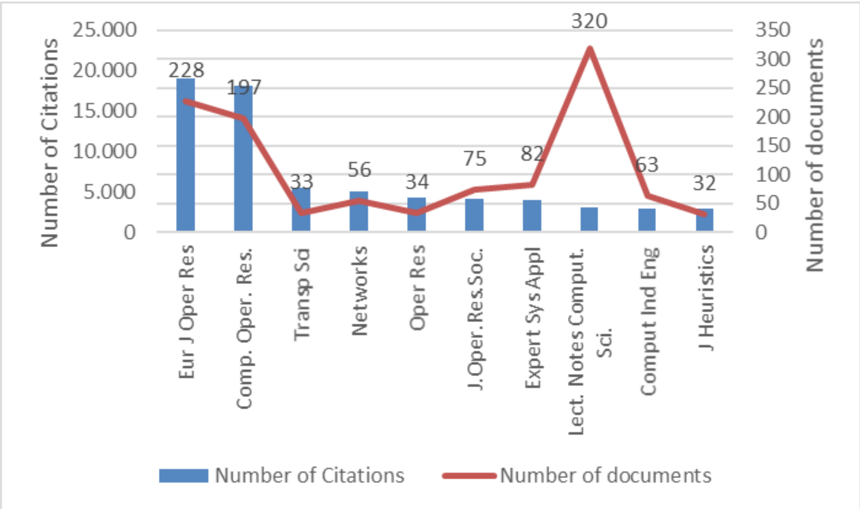

Figure 8: Top 10 Journals by number of citations (1971-2017), Source: Own elaboration from SCOPUS data

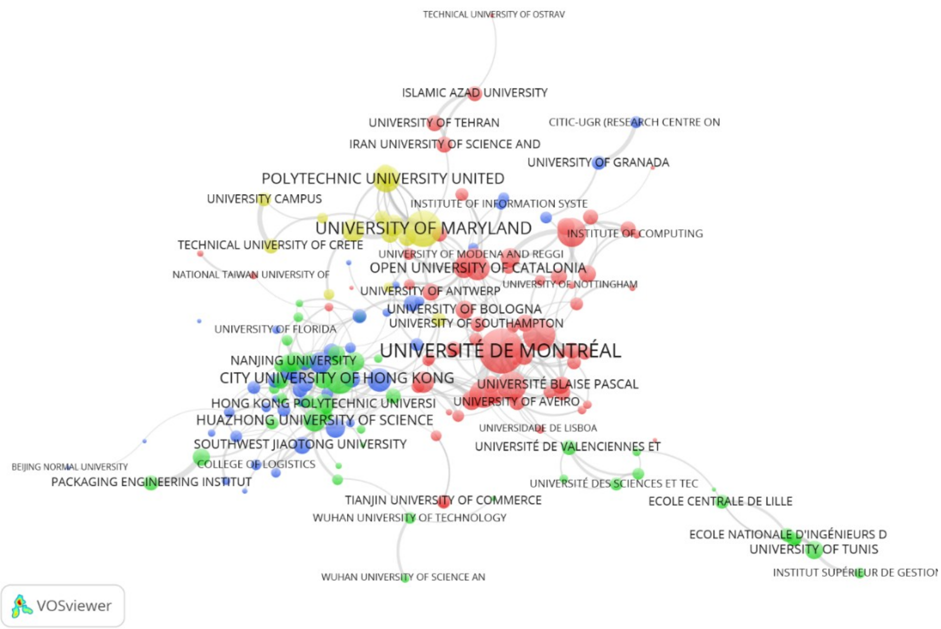

Figure 9: Network of top 100 based on institutions collaboration for VRP scientific production, Source: Own elaboration. Note: The size of the circle indicates the strengh of cooperation of the item.

In Figure 9, a network of collaboration made in VOSviewer software is shown where the Université de Montréal, the University of Maryland and the University of Hong Kong outstand by its size, the centred position they have and the number of links coming out of them. These institutions are likely to be internationalized and are also good options for knowledge transferences between academic institutions and industry.

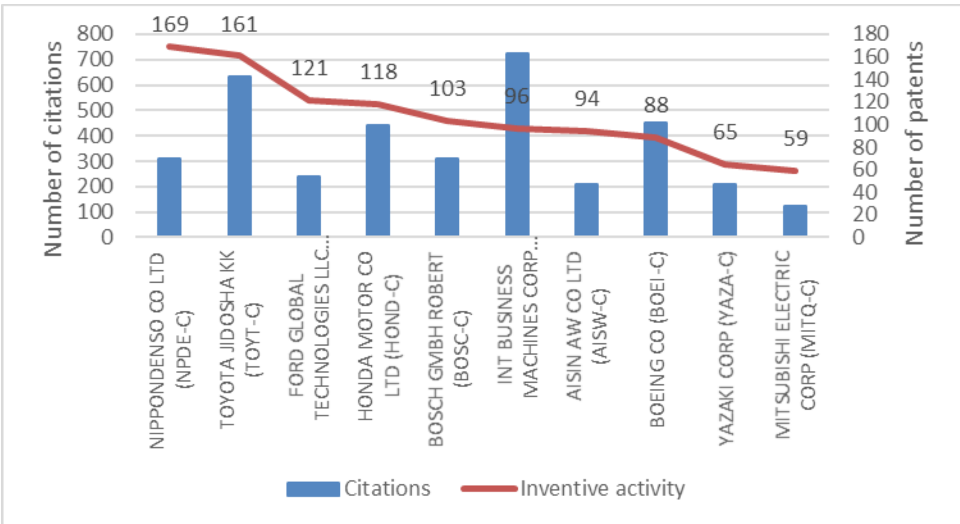

Figure 10: Top 10 institution by inventive activity (1991-2017), Source: Own elaboration from SCOPUS data

For inventive activity, a whole new scenario is shown in Figure 10 where Nippondenso Co Ltd. (NPDE) from Japan occupies the first place with 169 patents, second place goes for Toyota Jidosha KK (TOYT) from Japan with 161 patents. Then, Ford Global Technologies LLC (FORD) from the US, Honda Motor Co Ltd (HOND) from Japan, Bosch GMBH Robert (BOSC) from Germany, International Business Machines Corp. (IBMC) from the US, Aisin Aw Co. LTD. (AISW) From Japan, Boeing Co (BOEI) from the US, Yazaki Corp (YAZA) from Japan and Mitsubishi Electric Corp (MITQ) from Japan. To summarize, there is a total of 6 Japanese companies, 3 US companies and 1 German company. 7 companies are automotive manufacturers, 1 company is an aircraft manufacturer (BOEI), 1 company is computers manufacturer (IBMC) and 1 company is specialized in car navigation systems manufacturing (AISW).

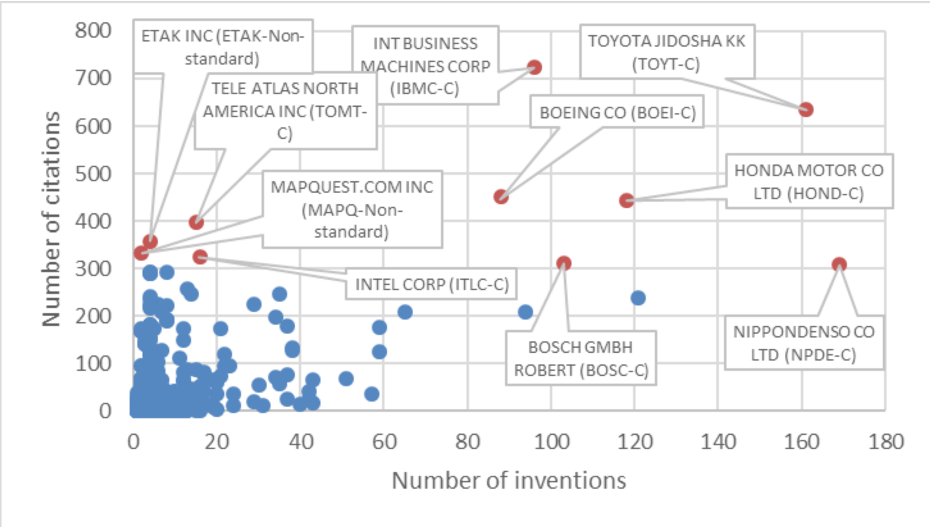

Figure 11: Highlighted applicants based on their inventive activity and industrial impact (1991-2017), Source: own elaboration from Web of Science data

Industrial impact represented in Figure 11 is somewhat consistent with the inventive activity. The company with most industrial impact is IBMC (723 citations) followed by TOYT (634), BOEI (451), HOND (442), Tele Atlas North America Inc from the US (TOMT, 396), Etak Inc from the US (ETAK, 356), MAPQUEST.COM INC from the US (MAPQ, 332), INTEL CORP from the US (ITLC, 324), BOSC (311) and NPDE (308). There are in total 7 companies from the US, 3 from Japan and 1 from Germany. Companies like TOMT, ETAK and MAPQ are specialized in global information systems and navigation solutions and ITLC is a semiconductor manufacturer.

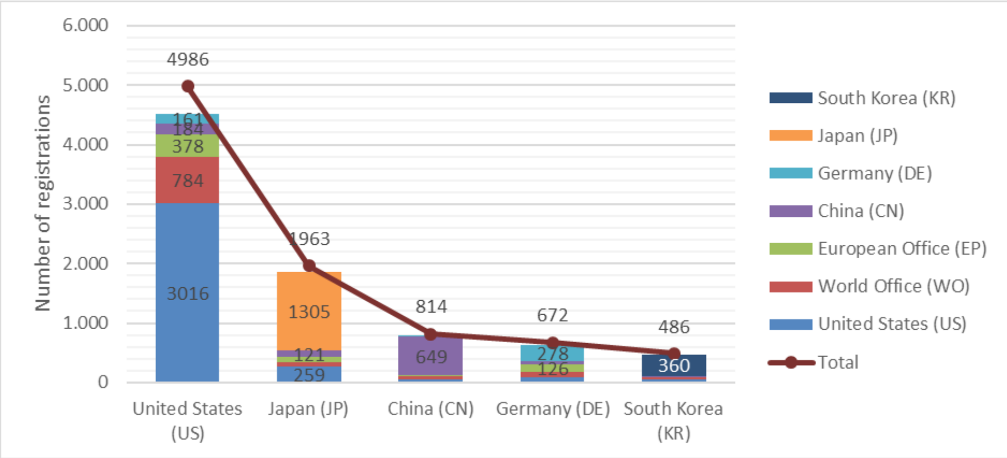

Figure 12: Potential markets for patents of VRP related technologies (1991-2017), Source: own elaboration from Web of Science data

Leading companies patenting VRP related technology tend to apply to offices in the same country as shown in Figure 12, this behaviour could mean that institutions are not making international alliances with partners in other countries. US applicants however, have a significant number of patents in WO, EP, CN and DE. Potential markets for each country are the local offices and the WO and the EP as there is no saturation in any of them. EP also becomes a potential market for some European countries, Germany is an example focusing 20% of its inventive activity in this office.

Figure 13 confirms a lack of collaboration not only with academic institutions but also with other companies. Japanese companies are the only ones who works together within the same group or even with different groups. The inexistence of remarkable academy-industry relations can be seen as an opportunity to make strategic incursions of knowledge transference. The most collaborative companies are the centered triangle of TOYT composed of Toyota Jidosha KK, Toyota Motor Co Ltd and Toyota Motor Corp. TOYT has a strong relationship with AISW and weaker but still relevant relationships with leading companies as NPDE and YAZA.

Scientific trends analysis

For trends in scientific production a sample of 100 keywords (rounded up from 95 of 15825 with confidence level of 95% and confidence interval of 10%) were selected and analysed through VOSviewer software which clustered information resulting in Figure 14 showing 5 trends as follows:

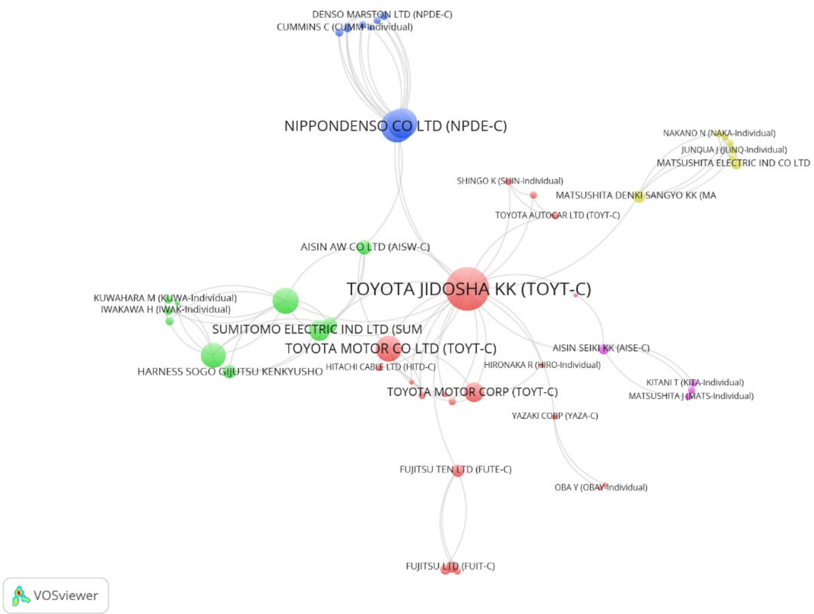

Figure 13: Network of applicants' collaboration for VRP scientific production (1991-2017), Source: own elaboration. Note: The size of the circle indicates the strengh of cooperation of the item.

i. Cluster No. 1 (Magenta): Combinatorial Optimization trend, where an emerging science called "combinatorial optimization" is shown for deep study of problems like VRP and others with similar structures.

ii. Cluster No. 2 (Green): Exact & Heuristic Algorithms trend, the early approaches to solve VRP characterized by being capable of finding a global optimum sacrificing computational efficiency.

iii. Cluster No. 3 (Red): Metaheuristic Algorithms trend, grouping solving methods for VRP that are faster but less accurate.

iv. Cluster No. 4 (Blue): Computational Efficiency trend, for focuses on the developing of more efficient algorithms for already existing and tested instances.

v. Cluster No. 5 (Yellow): Applications trend, because of the high interest on this trend concerning how VRP is used in case studies, it is going to be deepen.

Applications of the VRP consist in adapting the mathematical models to optimize one of various topics of concern in different contexts. A common and early variations is the Vehicle Routing Problem with Time Windows (VRPTW) where some time conditions must be met: the total duration of each route should not exceed a preset time, the service at a customer *i* begins in an interval $[e_i, l_i]$, and every vehicle leaves the depot and returns to the depot in the interval $[e_o, l_o]$ and the total time of all vehicles is minimized (Jean-François Cordeau, Laporte, Mercier, & others, 2001).

VRPTW are very convenient for enterprises that need a special management of time like bank deliveries, postal deliveries, industrial refuse collection, national franchise restaurant services, school bus routing, security patrol services and vendor deliveries for just-in-time manufacturing (Bräysy, 2003). Now then, there are other industries that need to adopt models that focus on other aspects.

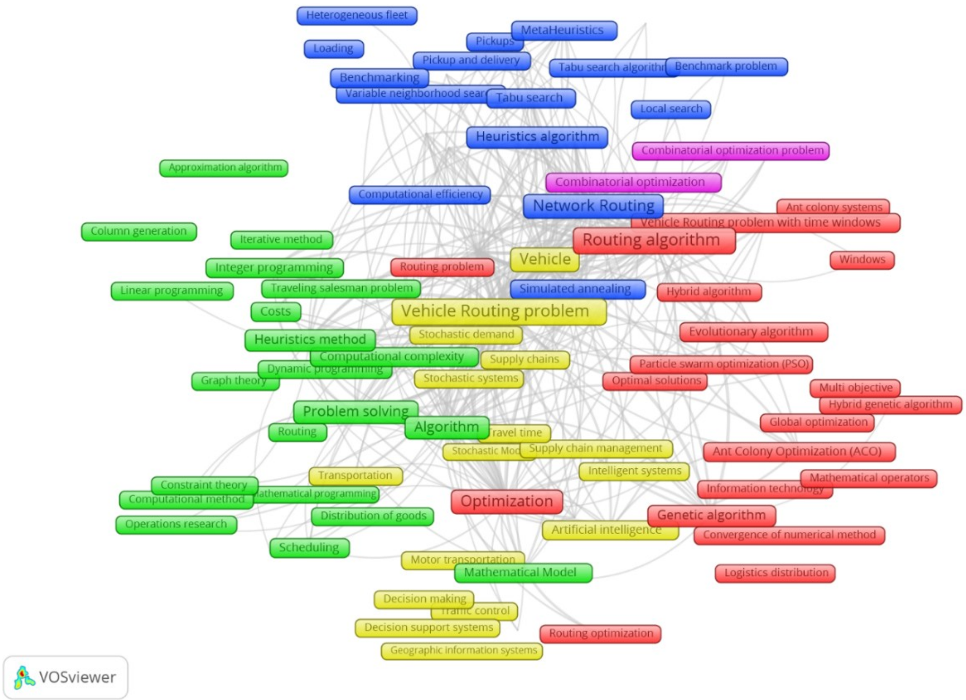

Figure 14. Top 100 VRP related keywords network (1971-2017). Source: own elaboration. Note: The size of the label indicates the strengh of cooperation of the item.

According to keywords and the literature, VRP are integrated in decision support systems (DSS) that use mapping platforms such as Google Maps (Santos, Coutinho-Rodrigues, & Antunes, 2011), technologies like Geographical Information Systems (GIS) (Ioannou, Kritikos, & Prastacos, 2001) and high quality solution algorithms such as heuristics and meta-heuristics to provide fast results. GIS technologies are essential tools for mapping, dynamic condition visualization and decision making (Chen, Peña-Mora, & Ouyang, 2011), alongside Global position systems (GPS), Radio Frequency Identification (RFID) and information technologies as data transmission technologies and software for topological treatment of network datasets (Zhu, Liu, & Qiao, 2013).

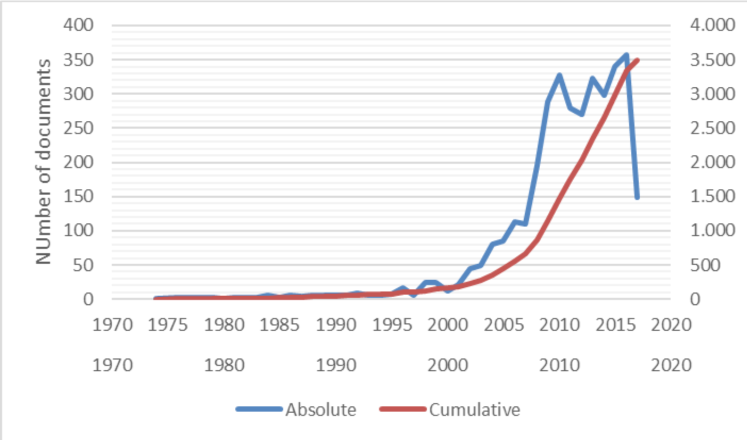

Figure 15. Applications keyword cluster lifecycle (1971-2017). Source: own elaboration from SCOPUS data

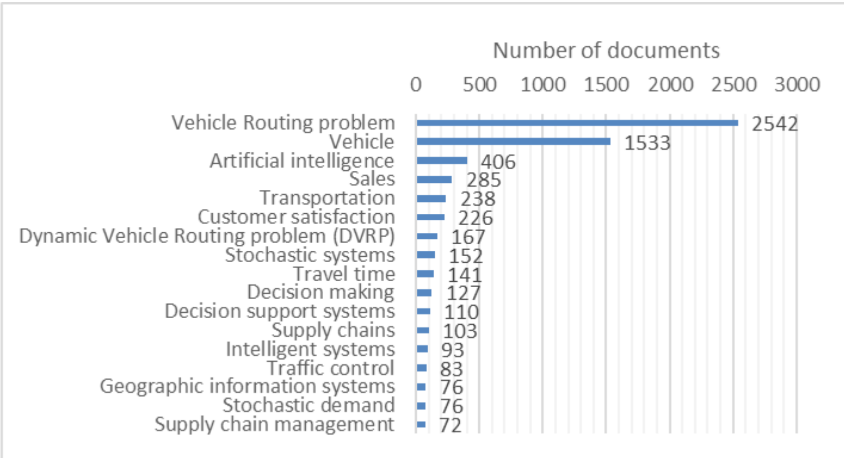

Figure 16: Application keywords cluster arranged by number of documents (1991-2017), Source: own elaboration from SCOPUS data

Real-time VRP based platforms can be results of that integration of technologies representing effective for supply chain management needs. In fact, there are some authors who work with stochastics demands as an attempt to explore more realistic problems. In the Stochastic VRP (SVRP), the demand has to be parametrized and the model changes according to the found distribution (Laporte, Louveaux, & Van Hamme, 2015), thus it is needed to explore extra costs related to surplus in the inventories or penalty costs related to shortage.

This approach is very useful in scenarios with a known probabilistic pattern and where special considerations have to be taken to solve the problem depending on the distribution of the stochastic variables (Laporte et al., 2015), stochastic customers in the case of VRPSDC (VRP with Stochastic Demands and Customers) (Gendreau, Laporte, & Séguin, 1996) or stochastic travel times due to traffic conditions and human handling of vehicles (Taş, Dellaert, Van Woensel, & De Kok, 2013). Uncertainty can also be made part of VRP modelling by using fuzzy logic techniques in the algorithms when precise data to estimate demand does not exist (Teodorović & Pavković, 1996).

A similar variant is Dynamic Vehicle Routing Problem (DVRP) where the information that serves as input data is revealed or updated during the period of time in which operations take place and generally corresponds to user requests (Berbeglia, Cordeau, & Laporte, 2010). A clear example of this is vehicle traffic information that can be obtained in real time from databases and the model being able to change the current state of the solution to find a better route (Gupta, Heng, Ong, Tan, & Zhang, 2017) and massively talking, controlling traffic itself.

However, for all this to come to reality, mathematical formulation of VRP models alone is not enough. As the number of costumers grow, so does the complexity of the objective function or the restrictions. Thus, the pure iterative method will become useless because of the huge amount of time that will be needed to solve the problem. Just to give an idea, a simple 15 nodes problem will have 15! ways to arrange the arcs, that is 1.307.674.368.000 iterations.

That's the reason why new solving algorithms must be developed, mixing exact algorithms, heuristic and metaheuristics that fit each specific problem, that allow a shorter overall processing time or that provide better results. Combined methodologies can be even more successful than pure techniques (Le Bouthillier & Crainic, 2005). Artificial intelligence and intelligent systems are then implemented on these attempts to create better solving techniques that are consistent in time and that are able to give real-time answers.

Patents analysis

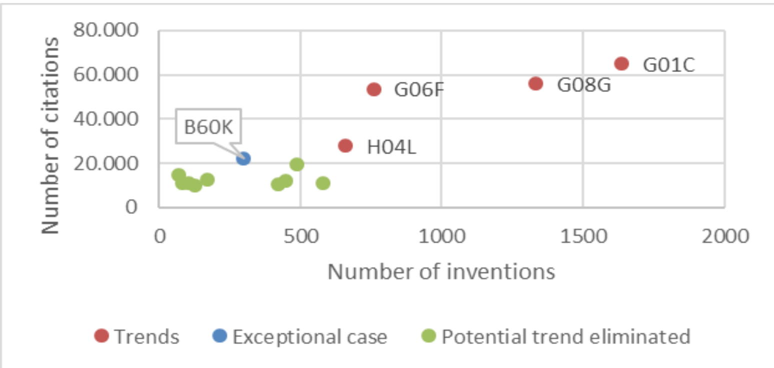

Figure 17: Industrial impact of preliminary patent trends (1991-2017), Source: own elaboration from Web of Science data

A sample of 5% of the most frequent patents by IPCR code representing the 60% of the whole inventive activity were extracted (14 IPCR codes of 273) and then another filter was made by number of citations, leaving 4 principal trends with high industrial impact as shown in Figure 17.

For each trend an exploration of patents and IPRC codes with more impact is done to give a better description of what's exactly patented. For the first trend, G01C, it is reflected in VRP inventive activity through patents of navigation instruments which can take external data like position, course, altitude, distances traversed of all kinds of vehicles, generally in order to make calculations that output routing guidance. To take that information, modifications to input/output of in-board computers are also commonly patented under this code.

The G08G trend is about traffic control systems, with patents regarding the measurement of traffic in real time, arrangements for giving variable traffic instructions based on existing information. Also, anti-collision systems generally for non-urban vehicles, signals of vehicle positions, scheduled vehicles positons and indications for traffic control are usually displayed in a map.

Table 2: Names of the trends selected related to VRP, Source: own elaboration from Web of Science data

G01C	Measuring distances, levels or bearings; surveying; navigation; gyroscopic instruments; photogrammetry or videogrammetry
G08G	Traffic control systems
G06F	Electric digital data processing
H04L	Transmission of digital information, e.g. Telegraphic communication

G06F complementizes previous trends by adding the computing power to process obtained data and translating into indications, maps, plans; all by autonomous devices or apparatus that are specifically designed for that purpose. Also, this trend plays a key role for measuring vehicle performance, recording relevant data for posterior decision making in the vehicle as maintenance or routing guiding that takes into account fuel levels.

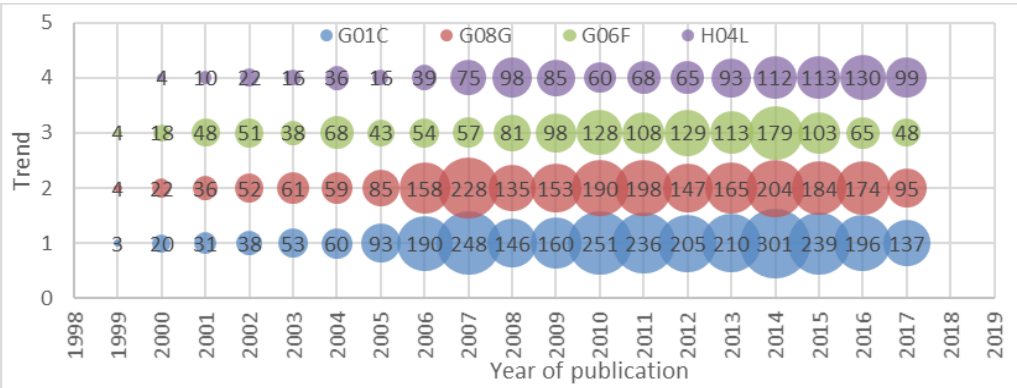

Figure 18: Technological dynamics on selected trends from Web of Science data

Finally, with H04L the scenario is expanded because of the possibility of sending and retrieving data from servers using the aforementioned devices and apparatus. Said servers could also make the computations, allowing to treat huge amounts of data and interconnecting vehicles to provide an efficient network routing.

G10C, G06F and H04L trends have an increasing inventive activity represented in Figure 19 meaning a growing stage. 2015, 2016 and 2017 are said to be incomplete years as in Figure 3 so are excluded from the analysis. As for G08G, it seems that its entering the maturity stage because the inability of surpassing inventive activity reached in 2007 and a relative stable trend from that moment.

CONCLUSION

According to its lifecycle VRP related scientific (from 1971) and patenting (from 1991) activity is in a growing stage with China as leading country for academic production and the United States as leading country for patenting. However, if impact is assessed a different scenario is detected in science where Canadian institutions becomes the top reference. Also, the University of Montreal, the University of Maryland and the University of Hong Kong have demonstrated being open institutions towards collaboration. Top journals are suggested in figure 8 for referencing and publishing, potential markets are explored in figure 13 for patenting. Keywords in scientific trend gives a hint that research on applications should be focused in real-time variants of VRP and so does patenting for technologies that support those variants in data retrieving, transmission of information and computing methods and capacity.

To summarise, the biggest opportunity in VRP related works is academy-industry integration that can be translated into notable alliances that make scientific and technologic impact. Integration is possible as trends in bibliography and patents have a notable connection, VRP theories can be used to develop devices, apparatuses and systems that measures relevant information for decision making and can be translated into prescriptive fast and efficient solutions for routing of one or several means of transportation. Case studies are recommended to convert existing and future VRP theories into powerful and realistic models for implementations of all kinds.

Further bibliometric and patent analysis could be focused in the specific context of some leading countries like China due to the inconsistences of its production and its influence, or Japan due to the small and closed but well-stablished network of collaboration in patenting.

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