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Capacitated vehicle routing problem for PSS uses based on ubiquitous computing: An emerging markets approach

Alberto Ochoa-Ortíz [a], Francisco Ornelas-Zapata [b], Lourdes Margain-Fuentes [b], Miguel Gastón Cedillo-Campos [c], Jöns Sánchez-Aguilar [d], Rubén Jaramillo-Vacio [e] & Isabel Ávila [a]

[a] *Universidad Autónoma de Ciudad Juárez, Ciudad Juárez, México. alberto.ochoa@uacj.mx*
[b] *Universidad Politécnica de Aguascalientes, Aguascalientes, México. francisco.ornelas@upa.edu.mx, lourde.margain@upa.edu.mx, mc140002@alumnos.upa.edu.mx*
[c] *Instituto Mexicano del Transporte, Salfandia, Querétato; México. gaston.cedillo@imt.com*
[d] *Instituto Tecnológico de Querétaro, Querétaro, México. jonssanchez@gmail.com*
[e] *CIATEC, Guanajuato, México. ruben.jaramillo@cfe.gob.mx*

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Abstract
The vehicle routing problem under capacity constraints based on ubiquitous computing in a perspective of deploying PSS (Product-Service Systems) configurations for urban goods transport, is addressed. It takes into account the specificities of city logistics under an emerging markets context. In this case, it involved: i) low logistical capabilities of decision makers; ii) limited availability of data; and iii) restricted access to high performance technology to compute optimal transportation routes. Therefore, the use of free download software providing inexpensive solutions (time and resources) is proposed. The paper shows the implementation of results to a software tool based on Graph Theory used to analyze and solve a CVRP (Capacitated Vehicle Routing Problem). The case of a local food delivery company located in a large city in Mexico was used. Based on small fleet vehicles with the same technical specifications and comparable load capacity.

Keywords: Graph theory; vehicle routing; city logistics; ubiquitous computing and product-service system.

Problema de enrutamiento de vehículos basado en su capacidad para SPS utilizando cómputo ubicuo: Un enfoque de mercados emergentes

Resumen
El problema de ruteo de vehículos bajo las limitaciones de capacidad y basado en computación ubicua desde una perspectiva relacionada con PSS (Producto-Servicio de Sistemas) para desarrollar configuraciones para el transporte urbano de mercancías es abordado. Éste trabajo considera las especificidades de la logística urbana bajo un contexto de mercados emergentes. En este caso, involucra: i) bajas competencias logísticas de los tomadores de decisiones; ii) la limitada disponibilidad de datos; y iii) restringido acceso a tecnología de alto desempeño para calcular rutas de transporte óptimas. Por lo tanto, se propone el uso de un software libre que proporciona soluciones de bajo costo (en tiempo y recursos). El artículo muestra la aplicación de los resultados de una herramienta de software basado en la Teoría de Grafos utilizado para analizar y resolver un CVRP (Capacitated Vehicle Routing Problem). Se utilizó el caso de una empresa local de distribución de alimentos situada en una gran ciudad de México. Sobre la base de una flora de vehículos pequeños, todos con las mismas especificaciones técnicas y una capacidad de carga comparable

Palabras clave: Teoría de grafos; rutas de vehículos; logística de la ciudad; computación ubicua y el sistema producto - servicio.

1. Introduction

For companies operating in emerging markets, the continuous upgrades in client's requests are result from a challenging continuous improvement process. First, because they need to propose the right level of satisfaction to their clients, and second, because they are constrained to achieve the financial goals required to maintain their operations in spite of the infrastructure faults and other external components reducing their logistics performance [1].

However, because of the important market opportunities to PSS, companies are concerned to improve their processes and capabilities. Under a dynamic competition environment, to increase logistics capabilities has become even more urgent, especially due to the costs of allocating clients to routes and the distribution expenses included then in the total cost [2]. This can be done with the help of new technologies (ICT, ITS), which seem necessary mainly for final distribution of goods to urban areas [3]. Moreover, the access to new technologies, already difficult in developed economies, is extremely expensive for new economies, so compensation of those costs by a better possibility of optimization can be a lever to the deployment of those technologies. This can be done via the implementation of Product-Service-Systems (PSS). PSS is defined by as *"a system of products, services, networks of players and supporting infrastructure that continuously strives to be competitive, satisfy customer needs and have lower environmental impact than traditional business models"* [4]. In this way, the quantity of materials consumed in the product's entire life can be reduced [5], but also the service component can be an important complement to the product itself [6]. This can be then an argument to deploy driving support devices that would be interfaced to a central server where the entire route sets of the company are optimized, GPS-based devices that propose route optimization for drivers or other ICT and ITS devices (product) that include route optimization solutions (service) for drivers or companies. Those services will then be based on vehicle routing.

Vehicle routing is not a new problem; its study arose in the mid-20th century with the model of the traveling salesman problem (TSP). In fact, a lot of research has been entirely devoted to these problems [7][8][9][10]. In the last few decades the development of software tools for solving vehicle routing problems has increased, essentially based on conceptual models inspired by biological systems, artificial intelligence (data mining, bio inspired algorithms and augmented reality), mathematical theories, among others [11]. However, this specialized knowledge is out of reach for decision makers in emerging markets where logistics business is continuously growing. Moreover, software is in general developed in a "service" perspective, without taking into account the "product" that will be associated to this service. Thus, based on the regional case of a third party logistics company located in Ciudad Juarez (State of Chihuahua, Mexico), the objective of this paper is to expose the results of an implementation of a software tool to analyze and solve CVRP (Capacitated Vehicle Routing Problem). At the same time, based on ubiquitous computing, a friendly-user platform running on an intelligent device was developed. Coupling the device to the vehicle fleet optimization service provided by the CVRP algorithm with ubiquitous computing is then a possible PSS configuration that is here tested. The paper is then adapting advanced techniques of optimization to a real case with the aim of testing a possible PSS configuration.

This paper is organized as follows. In Section 2, a conceptual revision of graph theory and CVRP, as well as a brief description of free-download software is described. In Section 3, the problems to be solved as well as detailed explanations related to solution procedure are shown. In Section 4, the computational results are presented and a discussion thereof is made. Finally, in Section 5, as conclusion, the importance of technology-based product-services more adapted to challenges that enterprises face when operating in emerging markets, as well as future research are presented.

2. Background

2.1. Graph Theory

Graph theory is a powerful tool to solve vehicle routing problems. As well as distribution routes, graphs are discrete structures composed by vertices, which are connected by arcs. Thus, a directed graph is denoted by G = (V,A), where V is an empty set of elements called vertices and A is a set of arcs. Each α ε A has two vertices of V, i, j, i≠j associated, where i is the initial point of the arc, and j is the terminal point. The arc α is also denoted by (i, j), thus referring to the source vertex to the destination vertex and arc [12].

2.2. Vehicle routing problems with capacity constraints (CVRP)

The CVRP is a fundamental combinatorial problem with applications in logistics optimization. In the last two decades, because of innovative algorithms, and increased capabilities of computer equipment, major advances in solution techniques have been achieved [2]. From a general point of view, in the CVRP, a finite set of cities and the costs of travels between them are given. Thus, a specific node is identified as the vehicle depot and the rest as clients. Each client corresponds to a location where an amount of a single product is delivered. The amounts required by customers are predetermined and cannot be divided. In other words, they have to be delivered by one vehicle at a time. In the simplest version it is assumed that vehicles are homogeneous and therefore, have the same maximum capacity [12]. Based on the graph theory, CVRP is formulated as a complete graph G = (V, E) where V = {0, 1, ..., n} is considered to be the set of vertices and E a set of edges between two vertices. In this paper, vertex corresponding to vehicles is noted as 0, and vertices {1,..., n} are different customers. At the same time, for an arc e = [i, j], c_e is the cost of going from node *i* to node *j*. Furthermore, a fleet of K vehicles is supposed, each of capacity Q. Finally, customer demands *i* are denoted by d_i. In fact, d is defined as the distance between two nodes, while, *i* is defined as the quantity of product or service to be delivered to the customer. A binary variable x_e indicates whether edge *e* is on the path of a vehicle or not [12][13]. The mathematical formulation is expressed as follows:

$$min \sum_{e \epsilon E}^{(i,j)} C_e X_e \quad (1)$$

$$x(\sigma(\{i\}) = 2 \; for \; all \; i \; \epsilon \; V \backslash\backslash \{0\} \quad (2)$$

$$x(\sigma\{0\}) = 2K \tag{3}$$

$$x(\sigma(S)) \geq \frac{2}{Q}\sum_{i\in E}^{n} d_i \; for\ all\ S(V\{0\}) \tag{4}$$

$$X_{\emptyset} \in \{0,1\} = 2\ for\ all\ e \in E \tag{5}$$

Thus, equation (2) states that each client is visited exactly once by a vehicle. Equation (3) states that the depot's capacity is 2K. Furthermore, when inequalities in (4) and (5) are done, it drives a bi-connectivity of the entire solution. As a result, the number of customers to be served exceeds the maximum capacity (Q), and the same vehicle cannot visit them [14]. However, the range of models for solving vehicle routing problems is extensive. This is caused by the large diversity of variables of every specific problem and the uncertainty involved in [7], [15] and [16].

2.3. Software tool

Due to complexity when solving CVRP, our research approach took into account the specific characteristics of city logistics operations under an emerging markets context that in this case involved: i) low logistical capabilities of decision makers; ii) limited availability of data; and iii) restricted access to high performance technology to compute optimal transportation routes. Thus, since the use of software is a powerful tool to improve logistics competitiveness when logistics capabilities of decision makers are low, the opportunity to use a friendly-user and low-cost software was identified. "*Graphs*" is a free software tool for building, editing and analyzing graphs. It is also useful for teaching, learning, and practicing graph theory as well as related disciplines such as operations research, network design, industrial engineering, and logistics systems, among others. It incorporates algorithms and functions that allow analyzing real problems [16]. The process of software development as modules has an interface for building and editing graphs (*.dll). The user can freely draw a selected graph to analyze it without worrying about the solving process used later. This software displays a signal if a particular analysis is not feasible. However, due to the freedom provided by the software to the user in designing graphs, if decided, any scenario could be taken into account (including not feasible solutions). It clearly implies a great computational complexity to the software. "*Graphs*" allows building both directed graphs as undirected. The user decides the distribution of the graph, although the program can support him with other utilities that automatically draw the graph (tree format, radial, organic force directed flow, random, among others). The user can also import or export the coordinates of the nodes, with the possibility of adding a map as part of the graph's background layer [19][20][21]. It can also calculate the distance between nodes and enter this value automatically (or as a proportional cost) in the edges of the graph. Thus, based on the information associated to every node, it identifies the shortest path, and then, it defines the next node to be reach.

Table 1.
Load demands.

ZONE	LOAD DEMANDS
Minarete	307 Ton.
Anapra	27 Ton.
Paraíso	57 Ton.
La Cuesta	187 Ton.

Sources: Dataset from CIS Research Center, UACJ.

3. Real world applications

For third party logistics companies operating in emerging markets, especially small and medium enterprises (SME), vehicle routing problems are frequently solved without a strong scientific basis. In fact, most of the SME companies design their logistics solutions based on the so-called "*expert judgment*". In that context, the most usual problems in decision-making are to reduce transportation costs, and at the same time, to improve customer service by finding the best routes that minimize the total distance or transit time. However, in SME companies running operations in emerging markets, modern software tools are frequently seen as expensive and complex tools to design logistics solutions. Consequently, free download software as "*Graphs*" represents a useful first step to improve solving capabilities in logistics.

3.1. Case description

The information here analyzed was provided for a third party logistics company with operations in ciudad Juarez (State of Chihuahua, Mexico). Due to the complexity when analyzing all its logistics operations, a more specific case concerning the distribution of perishable food was created. A fleet of 17 vehicles with the same technical specifications and similar load capacity (15 tons) composed this case. Juarez City and its Metropolitan Area were defined as the geographical zone for this analysis. Destinations are concentrated on four zones of the city: i) Minarete ii) Anapra; iii) Paraíso; and iV) La Cuesta. The load demands are presented in Table 1.

To design a CVRP solution using the software "*Graphs*", the three steps suggested by Rodríguez [20]were used: i) to build the matrix of distances between cities; ii) to state all the nodes with their respective supply and demand of load and constraints; iii) to establish the operational variables of vehicles.

3.2. Matrix of distances

First, taking into account the distances between origin and destination nodes, the matrix of distances was built (see Table 2) and all the data were programed into the software.

Table 2.
Matrix of distances in kilometers.

Neighborhood/Distance	Minarete	Anapra	Paraíso	La Cuesta	Manantial	Rododendro	Riveras
Minarete		9.15	7.88	10.57	9.89	13.97	5.34
Anapra	9.15		5.76	6.74	3.44	18.97	10.45
Paraíso	7.88	5.76		5.12	7.24	8.85	4.48
La Cuesta	10.57	6.74	5.12		2.56	9.88	12.46
Manantial	9.89	3.44	7.24	2.56		4.14	8.36
Rododendro	13.97	18.97	8.85	9.88	4.14		6.67
Riveras	5.34	10.45	4.48	12.46	8.36	6.67	

Sources: Dataset from CIS Research Center, UACJ.

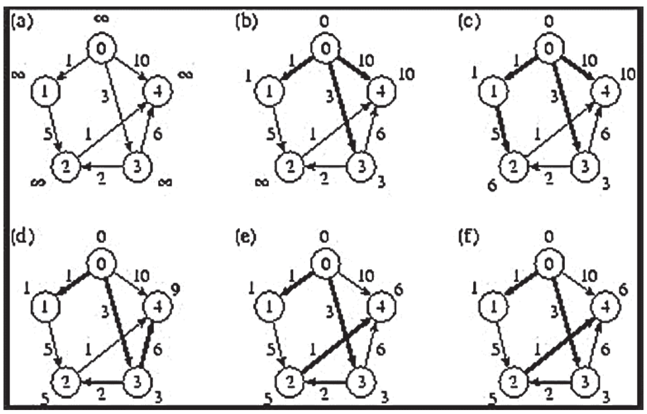

Figure 1. Graphs related to the problem
Source: [12].

3.3. Stating the nodes

Second, based on the matrix of distances and demand loads, a set of nodes Origin-Destination for each neighborhood was stated. As a result, the critical graphs related to the problem were identified (see Fig. 1).

3.4. Operational constraints

Third, the vehicle constraints were given by the company's business context. In fact, legal, financial, and operational aspects of the operational context were analyzed. These constraints were calculated taking into account several specific company's operational policies as:

i) a vehicle runs operations 10 hours a day;
ii) it runs 6 days a week;
iii) it operates 4 weeks per month;
iv) the average operational speed is 60 km/hr; and
v) maximum distance for all the programmed trips were 1,485 km/per month.

Other variables are exposed in Table 3.

Figs.2 and 3 present how different nodes were generated as well as possible graphs related to the implementation of an optimal route for each journey. The model here presented considered the weather implications, which are considered as difficult 4 months a year

Table 3.
Variables

Variables	Units
Demand and supply of cargo	Tons / Month
Fixed and variable costs	$ 7.00 per month
Capacity of vehicles	Tons / Month
Maximum distance	Miles / Month
Fixed Cost	$ 2'500,000.00 per 17 months for each vehicle
Variable Cost	$ 2,750.00 / km for each vehicle
Capacity	385 Tons / month

Sources: Dataset from CIS Research Center, UACJ.

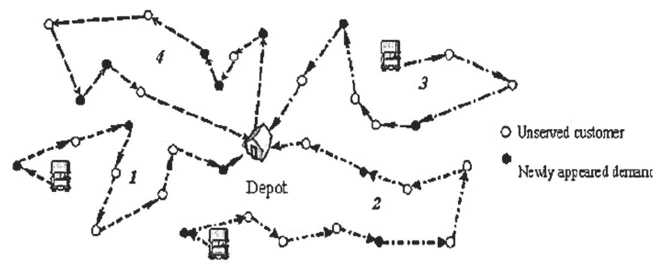

Figure 2. Implementation results.
Source: [8].

More specifically, the model here proposed adjusts the optimal values of each node. As a result, it was the sixth iteration that showed the optimal route by taking into account: i) time restrictions; ii) weather conditions; and iii) waiting time to load and unload.

3.5. Ubiquitous computing

Since a user could move from one computing environment to another, ubiquitous computing poses a number of challenges in designing software architecture. Thus, to design user interfaces for mobile devices should take into account a number of constraints. Indeed the limited screen is to show the information. Since there is nowadays a wide range of screen sizes and resolutions, an interface

Figure 3. Driver using our Intelligent CVRP to Ciudad Juarez.
Sources: Intelligent software development in CIS Research Center, UACJ.

should be designed to be used on most of devises available on the market. For this project, the proposed model was developed in Android API, and the programming interface was in XML. Data Server Communication is the most important component because it communicates to the server that allows the devise to send the GPS position obtained by receiving the processed image and location map (see Fig. 3).

4. Results

Because of the restrictions related to each route, our tool defines additional routes feasible solution scenarios. Each scenario analysed considers possible changes in the route depending on the vales generated and assessed by Djikstra algorithm. This enables us to solve dynamically the CVRP. The results obtained are presented in Table 4.

Route 1 is covered by a vehicle with a capacity utilization of 100% (385 tons per month). Likewise, Route 2 is covered by a vehicle with a capacity utilization of 100% (385 tons / month) as shown in Table 5.

The results obtained using the software "Graphs" to solve the proposed CVRP problem were implemented by the third party logistics company with an improvement of 27% in their operations. Since vehicle routing problems were frequently solved based on the so-called "expert judgment", the proposed model and the informatics tool developed based on the ubiquitous computing approach, significantly improved their logistics capabilities. They both reduced transportation costs, and at the same time, improved the capacity utilization rate of the vehicle fleet. Furthermore, ubiquitous computing solution is allowed company to improve customer service, and can be associated to ICT products and solutions like mobile phones or vehicle devices (GPS, driving support tools, etc.). It is now offering superior logistics services that other local logistics providers, with limited technological exposure, cannot provide. Since differentiating customer service is critical in the current competitive world, this tool could improve company's profitability.

Table 4.
CVRP solution

Description	Route 1	Route 2
Travel 1	Manantial, Minarete	Minarete –Paraíso
Travel 2	Minarete, Anapra	Paraíso – Anapra
Travel 3	Anapra -Rododendro-Riveras	Anapra – La Cuesta – Riveras
Total distance in KM	247.7	158.7
Total cost in USD	$29,750	$29,750
Variable cost	$57,425	$70,285
Capacity Utilization Rate	385/385 = 100%	385/385 = 100%

Sources: Dataset from CIS Research Center, UACJ.

Table 5.
Performance indicators

Variable costs due to delays (VC)	$135,700.00
Route's fixed costs (FC)	$57,425.00
Total cost in USD (FC + VC)	$193,125.00

Sources: Dataset from CIS Research Center, UACJ.

5. Conclusions

In an emerging market business context where most of local companies do not have a clear logistics strategy. Operational issues are driven by a dynamic competition to provide the right level of satisfaction to clients, and constrained by external difficulties (infrastructure inefficiencies, legal framework, etc.) to achieve their financial goals. Nevertheless, favorable market opportunities to PSS provide an incentive to improve their processes.

Thus, since most of the local practitioners do not have enough logistics capabilities, the use of free download software to solve complex logistics problems, is the first step to increase logistics competitiveness. In fact, the results achieved with this implementation convinced the company about the importance of the software technology to improve their logistics operations.

The results proved that this approach optimizes costs and consequently, provides a competitive advantage to a company running operations under high operational costs [11]. Clearly, setting the restrictions for modeling vehicle routing problems plays an important role in obtaining an optimal and practical solution. In these cases, it is critical to balance theoretical approaches with a proper planning of routes to avoid, for example, movements of empty vehicles.

Technology-based product-services more adapted to challenges that enterprises face when operating in emerging markets could be a competitive advantage. Our work offered a tool that considered solution scenarios to design routes in emerging markets cities, where logistic abilities are low. Possible product-service systems applications of VRP-based solving tools that can be examined in future include vehicles (leasing services with fleet optimization based on CVRP), mobile devices (the Android application can be associated to mobile phone offers for distribution companies), GPS-based vehicle devices or vehicle-sharing systems, among others.

The proposed model provides useful information to decision makers to define and reduce waiting times when distributing perishable goods in metropolitan zones. Results highlight the quantitative benefits achieved when technological tools are implemented taking into account the specific needs of the operational context. In addition, the importance of tools more adapted to logistical challenges that enterprises face when operating in emerging markets is highlighted. Finally, as future research, from a theoretical perspective, the solution here proposed will be improved by the use of estimation of distribution algorithm [21][22][23][24].

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C.A. Ochoa-Ortiz, B.S. ’94, Eng. Master ’00, Ph.D. ’04, Postdoctoral Researcher,’06, and Industrial Postdoctoral Research ’09. He joined the Juarez City University in 2008. He has 7 BOOK, and 27 chapters in books related with AI. He has supervised 37 Ph.D. theses, 47 M.Sc. theses and 49 undergraduate theses. He participated in the organization of several International Conferences. His research interests include evolutionary computation, natural processing language, anthropometrics characterization and Social Data Mining. In his second Postdoctoral Research participated in an internship in ISTC-CNR in Rome, Italy. He collaborates with researchers from Irán, Kyrguistán and Cyprus. Dr. Ochoa is National Researcher (National Council of Science and Technology of Mexico – CONACYT) during eight years.

F.J. Ornelas-Zapata, received the Bs. Degree in Informatics (2001); Master in Computer Science (2007); PhD in Computer Science (2010). He is currently a research professor at the Polytechnic University of Aguascalientes and the Autonomous University of Aguascalientes. Her research area is Artificial Intelligence. Her research is on vehicle routing problems and parallel computing. He has 4 chapters in books related whit AI. He participated in the COMCEV’2007, COMCEV´2008, HIS´2009, MICAI’2010, CILOG´2014.

M.L.Y. Margain-Fuentes, inspired by the Software Engineering and Quality Systems Standards, begins her Mastery on Informatics and Information Technology in the Aguascalientes Autonomous University and finishes in the Windsor University in Ontario, Canada. Through the Doctor’s degree in Computation Sciences she gets the interest in researching Learning Objects and e-learning. She has outstand for her professional experience in the industry and government. She has worked as professor in bachelors and master’s degree. She has imparted several international conferences. She has participated in multiple software projects as assessor. She was for six years as Director of the Information Strategic Systems career and Software Engineering and for the last two year is a Director of Research and Postgraduate Department in the Aguascalientes Polytechnic University.

M.G. Cedillo-Campos, is a Professor in Logistics Systems Dynamics and Founding Chairman of the Mexican Logistics and Supply Chain Association (AML). Dr. Cedillo is National Researcher (National Council of Science and Technology of Mexico - CONACYT), Innovation Award 2012 (UANL-FIME) and National Logistics Award 2012. In 2004, he received with honors a Ph.D. in Logistics Systems Dynamics from the University of Paris, France. Recently, he collaborated as Visiting Researcher at Zaragoza Logistics Center as well as a keynote speaker at Georgia Tech Panama. He works in logistics systems analysis and modeling, risk analysis, and supply chain management, which are the subjects he teaches and researches in different prestigious universities in Mexico and abroad. Dr. Cedillo is the Scientific Chairman of the International Congress on Logistics and Supply Chain (CiLOG) organized by the Mexican Logistics and Supply Chain Association (AML), and coordinator of the National Logistics Research Network in Mexico supported by the program "*Redes Temáticas de Investigación*" of CONACYT.

J. Sanchez-Aguilar, Bs. Electrical Engineer; Master of Industrial Engineering; PhD in Industrial Engineering and Manufacturing; Currently works at the Technological Institute of Queretaro; He has published over 38 articles in refereed journals and international dissemination, IMPI awarded him five titles patents, has directed more than 10 graduate theses, and is a founding member of the Mexican Association of Logistics. Currently belongs to the National System of Researchers.

R. Jaramillo-Vacio, Has received BSc (2002), Master in Electrical Engineering (2005), Master in Management Engineering and Quality (2010). He has joint CIATEC (Conacyt Research Center) in 2010 to carry out his PhD research in the Industrial Engineering and Manufacturing. Since 2005 he is Test Engineer in CFE-LAPEM in dielectric test, partial discharge diagnosis at power cables. He is an author and coauthor of numerous published works, including book chapters, and over 27 articles related to his research. His main research interest includes partial discharge diagnosis, intelligence artificial, data mining, learning theory and neural networks.

L. I, Ávila, Bs. Industrial Engineering; Masters of Science in Engineering Student. His research is on vehicle routing problem used bio-inspired algorithms. She participated in CILOG'2014.