STATE OF THE ART IN SIMULATION-BASED OPTIMIZATION APPROACHES FOR VEHICLE ROUTING PROBLEMS ALONG MANUFACTURING SUPPLY CHAINS

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Abstract
Transport execution influences directly the operational performance of distributed production systems. In order to attain efficiency, many decisions have to be taken, such as, (i) the choice of best route which minimizes travelling distance, (ii) the definition of proper scheduling, which improves the displacement timing, and (iii) the selection of transportation mode. Transport routing and scheduling present stochastic characteristics, which can be described as functions of probability. In the recent literature, it has been suggested that complex stochastic problems can be solved using simulation-based optimization approaches (SBO). SBO combines the power of optimization heuristics with the advantages of simulation models which can evaluate the effect of parameter changes even on very complex systems. Since it is capable of capturing the relationships and interactions among various entities and subsequently identifying a good design or solution, SBO might represent a powerful support to decision-making in complex and stochastic situations such as transport routing and scheduling in distributed production systems. Furthermore, transport systems are highly dynamic, which have to adapt permanently to a variety of oscillations such as unpredictable demand, urgent requests of high priority, or disturbances such as vehicle crashes. On the technological frontier, the availability of system state data is facilitated by the introduction of cyber-physical systems and industry 4.0 concepts and technologies. Thereof, a new approach that employs the newly available data, enabling real-time revision of transport routing and scheduling as operations take place, embodies a research opportunity with potential practical impact. This paper aims to report the state of the art regarding SBO approaches applied to vehicle routing and scheduling problems with pick-up and delivery (VRPPD). The paper substantiate the relevance of developing new approaches for vehicle routing and scheduling along distributed manufacturing supply chains, which embrace the new possibilities created by the widespread employment of cyber-physical systems.

Keywords:
Logistic Execution Systems, simulation-based optimization, complex logistic systems, cyber-physical systems, VRPPD.

1 INTRODUCTION
Supply chain transport programming is characterized, both in business and in scientific research, as a relevant challenge, having great influence on the performance of industrial systems. In order to generate efficient processes, many decisions have to be made, for example, the best route to be traveled by a vehicle minimizing the distance, the time and, consequently, the transportation cost. In addition, Montoya-Torres et al. (2015) emphasize that physical distribution is one of the key functions in logistics systems, involving the flow of products from manufacturing plants or distribution centers through the transportation network to consumers. It is a very costly function, especially for the distribution industries. The Operational Research literature has addressed this problem by calling it the vehicle routing problem (VRP).
In the dynamic scenario of production systems, logistic and transport are subject to both internal and external oscillations. In this way, a new approach that enables real-time revisions of transport schedules as operations occur constitutes a research opportunity with potential practical impact.
The recent literature suggests the simulation-based optimization as a powerful tool for solving complex stochastic problems, which is based on the implantation of a simulation model in the optimization’s objective function. This approach combines the power of optimization heuristics with the advantages of simulation models which in turn can evaluate the effect of parameter changes even on very complex systems. However, in addition to stochastic influences that can be described as functions of probability, real systems have a feature that is neglected, for the sake of simplicity, in most models: they are highly dynamic systems that have to adapt permanently to a variety of external influences such as unpredictable demand, urgent requests of high priority, or disturbances such as vehicle crashes.
The purpose of this paper is to report the state of the art regarding SBO approaches applied to vehicle routing and scheduling problems with pick-up and delivery, identifying gaps through a robust literature review. Lastly, the development of a new SBO approach for VRP and scheduling along distributed manufacturing supply chains is fostered.
The organization of this paper starts with the current introduction. After that, section 2 will introduce the methodology used for the elaboration of the literature review, demonstrating the evaluation criteria and how the results were achieved. Chapter 3 will bring an overview of the papers and the results obtained by analyzing the selected articles. Chapter 4 will show a summary on the state of literature in VRP, VRPPD, Simulation-based Optimization in Logistic Execution Systems, Hybrid Approach in Logistics and Transport and Cyber-physical Systems. And finally the conclusion will be presented.

2 Review Methodology
The objective of this chapter is to present the methodology used to search articles on the topic of simulation-based optimization applied to logistic execution systems.
All the literature review was carried out based on “Web of Science” database, generating graphs and statistics through a structured methodology, focusing on more
relevant publications, number of publications over the years, most relevant authors and keywords related to the topic.

The keywords identified as most relevant related to the scope of the article were combined into the database for searching. The most relevant keywords considered were: “simulation-based optimization”, “vehicle routing problem” and “hybrid approach” combined with secondary keywords such as “pickup and delivery”, “meta-heuristic”, “transport scheduling”, “logistic” and “optimization”.

The first selection was made based on the titles, being selected those related to delivery problems (including, but not limited to, the travelling salesman problem), simulations and optimization problems. The second selection was done through the abstracts, identifying those that were according to the topic, or that could contain information relevant to the research.

For the third stage, with fewer articles, it was possible to select the most important ones through each paper’s introduction and conclusion analysis. The fourth and last step of the selection was the papers complete reading, resulting in eighteen titles used. Figure 1 shows the methodology of the systematic literature review.

3 OVERVIEW OF REVIEWED PAPERS

The following reports provide an analysis of the records obtained from the databases. These analyzes identify the most important authors, as well as the journals and keywords in the data, based on the set number of occurrences and citations.

Figure 2 shows an increasing trend in publications related to the subject, although it may not be statistically significant. Since in the 90’s, the number of publications has increased over time, and more publications have been obtained. These results correspond to previous studies, which verified that the use of simulation-based optimization in systems of logistic execution, adaptive programming or cybernetic physical systems are increasing over the years.

Figure 2. Methodology of the systematic literature.

The journals having more publications are presented in Figure 3. The journal that presented the largest number of publications over the years, with about 125 publications was the European Journal of Operational Research.

Figure 3. Main Publications.

From the report it is possible to obtain which keywords are most similar to those used in the search showed in chapter 2. The figure 4 shows these keywords.

Figure 4. Most cited keywords.

4 LITERATURE REVIEW

In this section, relevant theory will be presented to elucidate the state of the art regarding to simulation-based optimization applied in Logistic Execution Systems.

4.1 The Vehicle Routing Problem with Pick-up and Delivery – VRPPD

A classification of VRP with pick-up and delivery has been presented in the literature review paper of Parragh, Doerner, and Hartl (2008). They first define a main class of problems, which deal with the transportation of goods from the depot to the customers and from the customers to the
doi and then the second main class is identified as classical to all those types of problems where goods are transported between pick-up and delivery points may be paired or unpaired.

The single vehicle routing problem with pickups and deliveries (SVRPPD) is defined as follows. Let \( G = (V, A) \) be a graph where \( V = \{0, 1, \ldots, n\} \) is the vertex set, \( A = \{(i, j) : i, j \in V, i \neq j\} \) is the arc set, and \( C = \{c_{ij} : i, j \in V, i \neq j\} \) is a cost matrix defined on \( G \). Vertex 0 is a depot at which is based a vehicle of capacity \( Q \), while the remaining vertices represent customers. With each vertex \( i \in V \setminus \{0\} \) is associated a non-negative pickup demand \( p_i \) and a non-negative delivery demand \( d_i \), with \( p_i + d_i > 0 \). It is assumed that \( \sum_{j \in V} p_j \leq Q \) and \( \sum_{j \in V} d_j \leq Q \) for otherwise the problem is infeasible. In practice the products to be picked up are different from those delivered (Gribkovskaia et al. 2007).

The formulation and notation below was proposed by Tasan and Gen (2012) and adapted, using the formulation proposed by Luo et al. (2015), based on the paper scenario and objectives.

Notations:

- \( V \): Set of vehicles;
- \( J \): Set of customers;
- \( J_0 \): Set of Customers including depot;
- \( K_v \): Vehicle capacity;
- \( c_{ij} \): Distance between nodes \( i \) and \( j \), \( i \neq j \);
- \( d_j \): Delivery amount demanded by customer node \( j \);
- \( (i, j)_v \): Arc to be traveled by vehicle \( v \), from node \( i \) to node \( j \);
- \( l_v \): Load of vehicle \( v \) when leaving the depot;
- \( w_v = 1 \) if vehicle \( v \) is used and \( w_v = 0 \) if it is not being used;
- \( M \): Sufficiently large number [e.g. \( M \) can be calculated as the maximum value of either the total customer delivery and pick-up demands of the distances between each nodes as given in (1)].

\[
M = \max \left( \sum_{i \in J} d_i + \sum_{j \in J} p_j, \sum_{i \in J} \sum_{j \in J} c_{ij} \right) \quad (1)
\]

Then, the formulation is as follows:

Minimize

\[
\sum_{v \in V} w_v + \sum_{(i, j)_v} \sum_{v \in V} c_{ij} x_{ij} \quad (2)
\]

Subject to

\[
\sum_{i \in J} p_i = \sum_{j \in J} d_j = L, j \in J \quad (3)
\]

\[
\sum_{j \in J} x_{i,j} = \sum_{j \in J} x_{j,i} = 1, \quad i \in J \quad (4)
\]

\[
l'_{v} = \sum_{j \in J} x_{i,j}, v \in V \quad (5)
\]

\[
l_{j} \geq \ l'_{v} - d_{j} + p_{j} - M(1 - x_{j,j}), v \in V \quad (6)
\]

\[
l_{j} \geq \ l'_{v} - d_{j} + p_{j}, v \in V \quad (7)
\]

\[
l_{j} < \ K_v, v \in V \quad (8)
\]

\[
s_j > s_i + 1 - n(1 - \sum_{v \in V} x_{ij,v}), j \in J, i \in J, j \neq i \quad (9)
\]

\[
s_j \geq 0, j \in J \quad (10)
\]

\[
x_{ij,v} \in \{0,1\}, v \in V, i \in J, j \in J, v \in V \quad (11)
\]

\[
w_v \in \{0,1\}, v \in V, l_{v} \geq 0, \quad \text{and} \quad n \in \mathbb{N} \quad (12)
\]

\[
s_j \geq 0, j \in J \quad (13)
\]

The main objective (2) is to minimize the total set of used vehicles, the total distance travelled and, consequently, the travel total cost. Constraint (3) ensures that each customer node is served exactly once. Constraint (4) guarantees that for each customer node, same vehicle arrives at and leaves this node. Initial vehicle loads are calculated as in (5), each vehicle’s initial load is the accumulated demand of all customer nodes assigned to this vehicle. (6) Balances the load of vehicles after vehicles visit the first customer node on their route. For other customer nodes the loads of vehicles are calculated as in (7) similarly through their routes. (8) And (9) impose capacity constraint (11) maintains non-negativity of \( s_j \) and \( x_{ij,v} \) is a binary decision variable as in (12). Finally, a non-negative requirement (13) to the quantity of vehicles used.

### 4.2 Hybrid Approaches in Logistic and Transport

Lee and Kim (2000) propose a hybrid approach combining the analytic and simulation model. Operation time in the analytic model is considered as a dynamic factor and adjusted by the results from independently developed simulation model, which includes general production-distribution characteristics. The study obtains the more realistically optimal production-distribution plans for the integrated SC system reflecting stochastic natures by performing the iterative hybrid analytic-simulation procedure.

The procedure of the hybrid simulation-analytic approach is based on imposing adjusted capacities derived from the simulation model results. The procedure consists of the following steps (H. Lee and Kim, 2000):

Step 1. Obtain production and distribution rates from the analytic model.

Step 2. Input production and distribution rates to the independently developed simulation model.

Step 3. Simulate the system.

Step 4. If the results show that production and distribution can be produced and distributed within the capacity, then go to step 6. Otherwise go to step 5.

Step 5. Adjust capacity constraints for the analytic model based on the simulation results from step 3 and regenerate production and distribution rates and go to step 3.

Step 6. Production and distribution rates given by the analytic model may be considered to be optimal solutions.

Step 7. Stop.

### 4.3 Simulation-based optimization in Logistic Execution Systems

A model is a representation of a situation or reality, as seen by a group of people, and built to assist the handling of the situation in a systematic way. Enables better understanding of the context, to formulate strategies and opportunities to support and systematize the process of decisions (Atzori, Iera, and Morabito 2010). Historically, problem solving in complex systems involves modeling techniques and simulation (Longo, 2010). Therefore, should be analyzed which best simulator to be used to develop a robust optimization model capable of dealing with changes in system state, simulated in various scenarios. Finally, the performance of the adaptive method is evaluated through the test scenarios based on empirical data based on a real case, and after the...
evaluation results will be used for fine-tune the optimization heuristics. As mentioned, simulation is a powerful tool for the analysis and evaluation of complex and stochastic systems such as contemporary manufacturing and transportation environments (J. T. Lin and Chen, 2015). The complexity of most of real-world systems is related with their stochastic nature as well as to a multitude of internal and external interactions. However, it cannot provide an efficient optimization of these systems in relation to one or more performance indicators (e.g. waiting times, production costs, etc.). Optimization methods are mainly used if a complex system can be modeled by a simplified abstraction. Therefore, both approaches individually are limited in optimal decision making for complex and stochastic systems, such as scheduling transport and logistics systems. A promising approach to combine the strengths of both is simulation-based optimization (SBO). In this scenario, the simulation model is used as the objective function of the optimization and the optimization method determines the simulation parameters (Krug Et Al., 2002). Aspects like the physical configuration or operational rules of a system can be considered. Its applications have grown in all areas, assisting managers in the decision making process and enabling a better understanding of processes in complex systems (O’Kane, Spenceley, and Taylor 2000). Simulation can already be used to study systems in the design stage (Banks et al., 2000).

4.4 Cyber-physical Systems

With the emergence of the 4th Industrial Revolution and the consequent advance of automation, it is necessary for companies to reconcile human work with new technologies, facilitating the work that previously required a lot of time from employees and demanded a high level of care due to the great difficulty. Then, an important research focus for engineering emerges: how to correlate the production of a company with its logistics chain through intelligent computer systems capable of reading and interpreting input data and sending responses and work orders quickly and accurately.

As a consequence, the logistics system is evolving to a cyber-physical system (CPS) where physical system and information system interact with each other, called cyber-physical logistics system (CPLS) (Lai et al. 2013). Cyber-physical Systems - CPS assemble the cyber aspects of information system interact with each other, called cyber-physical logistics system (CPLS) (Lai et al. 2013). Cyber-physical Systems - CPS assemble the cyber aspects of computing and communications with the dynamics and physics of physical systems operating in the real world (Rajkumar et al., 2012).

Frazzon et al. (2013) introduces and reviews the social aspects of CPS and motivates future research towards Socio-Cyber-Physical Systems (SCPS) applied to production networks. The adoption of Cyber-Physical Systems (CPS) in production networks enables new potential for improved efficiency, accountability, sustainability and scalability. In terms of production and transport processes, materializing this potential requires customized technological concepts, planning and control methods as well as business model.

In terms of production and transport processes, materializing this potential requires customized technological concepts, planning and control methods as well as business models (K. J. Lin and Panahi, 2010).

5 DISCUSSION AND DIRECTIONS FOR FUTURE RESEARCHES

Bellow there are the 18 most important papers found in the literature regarding to the key-words of the bibliometric analysis according to the methodology presented in section 2.

<table>
<thead>
<tr>
<th>Nº</th>
<th>Year</th>
<th>Title</th>
<th>Author</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>2015</td>
<td>A cyber-physical systems architecture for industry 4.0-based manufacturing systems.</td>
<td>Lee et al</td>
</tr>
<tr>
<td>3</td>
<td>2015</td>
<td>Simulation optimization approach for hybrid flow shop scheduling problem in semiconductor back-end manufacturing.</td>
<td>Lin &amp; Chen</td>
</tr>
<tr>
<td>4</td>
<td>2015</td>
<td>A literature review on the vehicle routing problem with multiple depots.</td>
<td>Montoya-Torres et al</td>
</tr>
<tr>
<td>5</td>
<td>2014</td>
<td>A new VRPPD model and a hybrid heuristic solution approach for e-tailing.</td>
<td>Yanik et al</td>
</tr>
<tr>
<td>6</td>
<td>2013</td>
<td>A hybrid meta-heuristic for multi-objective vehicle routing problems with time windows</td>
<td>Baños et al</td>
</tr>
<tr>
<td>7</td>
<td>2013</td>
<td>Towards socio-cyber-physical systems in production networks</td>
<td>Frazzon et al</td>
</tr>
<tr>
<td>8</td>
<td>2013</td>
<td>Cyber-physical logistics system-based vehicle routing optimization</td>
<td>Lai et al</td>
</tr>
<tr>
<td>9</td>
<td>2012</td>
<td>A genetic Algorithm based approach to vehicle routing problem with simultaneous pick-up and deliveries</td>
<td>Tasani &amp; Gen</td>
</tr>
<tr>
<td>10</td>
<td>2012</td>
<td>Multiobjective quantum evolutionary algorithm for the vehicle routing problem with customer satisfaction</td>
<td>Zhang et al</td>
</tr>
<tr>
<td>11</td>
<td>2011</td>
<td>The vehicle routing problem with simultaneous pick-up and delivery based on customer satisfaction</td>
<td>Fan</td>
</tr>
<tr>
<td>12</td>
<td>2011</td>
<td>A simulation based approach for supply network control</td>
<td>Pirard et al</td>
</tr>
<tr>
<td>13</td>
<td>2010</td>
<td>A real-time service-oriented framework to support sustainable cyber-physical systems</td>
<td>Lin &amp; Panahi</td>
</tr>
<tr>
<td>14</td>
<td>2008</td>
<td>A survey on pickup and delivery problem</td>
<td>Parragh et al</td>
</tr>
<tr>
<td>15</td>
<td>2007</td>
<td>General solutions to the single vehicle routing problem with pick-ups and deliveries</td>
<td>Gribkowskaia et al</td>
</tr>
<tr>
<td>16</td>
<td>2006</td>
<td>A hybrid multiobjective evolutionary algorithm for solving vehicle routing problem with time windows</td>
<td>Tan et al</td>
</tr>
<tr>
<td>17</td>
<td>2000</td>
<td>Simulation as an essential tool for advanced manufacturing technology problems</td>
<td>O’Kane et al</td>
</tr>
<tr>
<td>18</td>
<td>2000</td>
<td>Optimal Production-distribution planning in supply chain management using a hybrid simulation-analytic approach</td>
<td>Lee &amp; Kim</td>
</tr>
</tbody>
</table>

In this search it could not be found papers which relates VRPPD methodology with simulation and optimization. Just a few papers were found as the example of the work presented by Lai et al (2014) that propose a vehicle initial routing optimization model with focus in minimize the total distribution cost considering uncertainties, vehicle capacity, customer time-window, and the maximum travelling distance as well as the road capacity. Tan et al (2005) proposes a hybrid multi-objective evolutionary algorithm
(HMOEA) that incorporates various heuristics for local exploitation in the evolutionary search and the concept of Pareto’s optimality for solving multi-objective optimization in vehicle routing problem with time windows. The proposed HMOEA is featured with specialized genetic operators and variable length chromosome representation to accommodate the sequence-oriented optimization in vehicle routing problem with time window.

Some other relevant papers involving scheduling with simulation and optimization were also found, for example the study of Pirard et al. (2010) with the focus is on the problem of strategic network design in the context of multi-site enterprise. The aim was to present a generic simulation model allowing the managers to evaluate various supply networks designs evaluation and also it takes into account control policies and scheduling of production activities. The simulation model allows carrying out local optimizations by dynamically allocation the customers’ demands and the replenishment orders placed by the sites of the enterprise so as to minimize a cost function. In short, the authors reinforce that the majority of the studied simulation models focuses on the redesign of the distribution network and is developed for a particular industrial case with a specific network structure and thus lack genericity models.

Lee and Kim (2000) presented in their article a hybrid method combining the analytic and simulation model for an integrated production-distribution system in supply chain environment. Lin and Chen (2014) present a study of simulation optimization approach for a hybrid flow shop scheduling problem in a real-world semi-conductor back-end assembly facility and the authors suggest that subsequent studies could employ different combinations of other search algorithms and acceleration techniques to improve solution quality while adopting the simulation optimization approach. For the authors the barriers that hinder the wide application of this approach are the long computation time required for simulation and the noise of performance evaluation using simulation under stochastic conditions.

Hernández-Pérez, Rodríguez-Martín, and Salazar-González (2016) study a hybrid heuristic approach to solve the multi-commodity pickup-and-delivery traveling salesman problem, which is a routing problem for a capacitated vehicle that has to serve a set of costumers that provide or require certain amount of m different products, with the objective to minimize the total travel distance. The algorithm has proved to be effective to solve difficult instances with up to 400 customers and 5 products.

Gribkovskaia et. al. (2007) have proposed a mixed integer programming model and heuristics for the single vehicle routing problem with pick-ups and deliveries in which each customer may be visited once or twice, giving rise to general solutions that encompass known solution shapes as Hamiltonian, double-path and lasso. The authors have also designed classical construction and improvement heuristics, as well as a tabu search heuristic for the problem. Their results show that the best known solutions generated by the heuristics are frequently non-Hamiltonian and may contain up to two customers visited twice. Tasan and Gen (2012) contribute to the VRP field by providing an efficient and effective genetic algorithm based approach that introduces highly feasible routes for vehicle routing problem with simultaneous pickups and deliveries (VRP-SPD).

6 CONCLUSION

This paper reviewed simulation-based optimization approaches applied to vehicle routing and scheduling problems with pick-up and delivery (VRPDD). The present work executed a bibliometric analysis and presented an in-depth analysis of optimization methods applied to logistic execution systems embracing technologies concerning to Industry 4.0.

It was found a considerable amount of optimization methods in the literature, although the number of papers applying simulation-based optimization (SBO) is still reduced, implying that the application of cyber-physical systems (CPS) is not fully explored. The availability of system data is facilitated by the introduction of the concept of CPS and with a new generation of distributed production systems technologies of Industry 4.0, which makes the simulation-based optimization approach a research opportunity with potential practical application. In fact, problems associated with the integration of transport and production systems have received increasing attention from researchers, due to the rapid evolution of telecommunication technologies, spatial positioning, information processing, as well as the advances observed in techniques of analysis, optimization and computing. In fact, the importance of the development and use of modern concepts and techniques for information exchange and decision-making is justified by the impacts on the more efficient use of available assets and the reduction of costs, lead time and supply chain vulnerabilities.

This paper comprises contemporary scientific research and contributes to the understanding regarding the improvement of scheduling and control of transportation and logistics systems by means of simulation-based optimization approaches based on data collected in real time. Developing and testing these approaches for vehicle routing and scheduling along distributed manufacturing supply chains which embrace the new possibilities created by the widespread employment of cyber-physical systems and combine simulation and optimization represent an interesting research frontier.

7 ACKNOWLEDGMENTS

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8 REFERENCES

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