Available online at www.sciencedirect.com

ScienceDirect

IFAC PapersOnLine 51-11 (2018) 968–973

An Inventory-Location Modeling Structure for Spare Parts Supply Chain Network Design Problems in Industrial End-User Sites

Tapia-Ubeda, Francisco, J.*, ** Miranda, Pablo, A., *** Roda, Irene***
Macchi, Marco* Durán, Orlando**

**Politecnico di Milano, Milano, 20156 MI, Italy*
(e-mail: franciscojavier.tapia@polimi.it, irene.roda@polimi.it, marco.macchi@polimi.it).
***Pontificia Universidad Católica de Valparaíso, Valparaíso, 2340025, Chile*
(e-mail: pablo.miranda@pucv.cl, orlando.duran@pucv.cl).
**** University of Portsmouth, Portsmouth, PO1 3DE UK, United Kingdom, Visiting Researcher*

Abstract: Traditional literature on Spare Parts Management from industrial end-user sites has not focused on the underlying Supply Chain Network. Thus, this paper analyzes the relevance of integrating Supply Chain Network design with traditional Spare Parts Management. With this aim, the paper proposes a network optimization modeling structure, with simultaneous decisions for warehouse locations and inventory control, allowing to optimize the Spare Parts Supply Chain Network costs.The model is specified for three traditional and commonly used Inventory Control Policies suitable for a variety of Spare Parts (i.e., (s, Q), (R, s, S) and (S-1, S)). The proposed integrated approach yields Spare Parts Supply Chain system performance improvements.

*Keywords**:** Spare Parts Management; Supply Chain Network Design; Supply Chain Management; Network Optimization; Inventory Control; Inventory Location Problem*

1. INTRODUCTION

Traditionally, the literature on Spare Parts (SPs) has been focused on both understanding the behavior of parts and developing techniques to properly manage them. According to literature and practitioners, managing SPs tends to be substantially different to other items (e.g., productive supplies, raw materials, commodities), due to the specific features that characterize their behavior (Huiskonen, 2001; Cavalieri et al., 2008; Martin et al., 2010; Wagner et al., 2012). But, extending the traditional focus to other issues and decisions, it is possible to find different relationships that impact the Spare Parts Management (SPM) decision process. Amon others, Supply Chain (SC) issues have been typically excluded from the analysis or assumed as given and fixed (Huiskonen, 2001; Wagner, et al., 2002, Martin, et al., 2010) in the viewpoint of industrial end-user sites (i.e., those that needs spare parts for the assets installed in their sites).

A relevant concern that must be considered into SPM is the underlying Supply Chain Network (SCN) that supports the SPs operations (e.g., transportation, inventories, warehousing). This paper analyzes the relevance of integrating Spare Parts Supply Chain Network (SP-SCN) design issues with traditional SPM. Optimization is focused on the SP warehouse location, consumption points assignment and inventory control decisions while minimizing the total system cost, consisting of operation and setting fixed costs, transportation costs, and inventory costs. For these purposes, it is assumed that spare part consumption points are the end of the SCN (i.e., assets in the industrial plant located at the end-user site associated with production activities that consume SP for replacements purposes when facing preventive maintenance activities or failure events).

One of the focuses of this paper is to establish and discuss some general relationships among SPM, SP Inventory Management, SCN and the underlying design problem. Additionally, this paper presents a generic single-commodity modeling structure to optimize the SP-SCN that considers simultaneously warehouse location and inventory control decisions. This structure aids to focus on the relevant issues that affect and must be considered on the specific models. In general, it is possible to address two relevant sets of decisions, one set related to the SCN design decisions and other set related to the Inventory Control Policies (ICPs) considered for managing the SP inventories across the SP-SCN. Naturally, the specific models, derived from the generic model, may consider different network structures and diverse suitable ICPs. Particularly, the basic structure considered into the generic optimization model is consistent with the standard and widely studied Facility Location Problems (FLPs) structure. Subsequently, three ICPs commonly adopted into SPs context are considered to specify the generic model, yielding three particular network optimization models. Notice that, these models belong to the family of Inventory Location Problems (ILPs) since they integrate warehouse location and inventory control decisions and costs (Erlebacher and Meller, 2000; Daskin, et al., 2002; Miranda and Garrido, 2004). Finally, a further discussion is made going deeper into the relationships between the mathematical models, the SPM and the SP-SCN. Consequently, a research agenda is presented considering different features that can be integrated into the mathematical models.

10.1016/j.ifacol.2018.08.482

The paper is organized as follows. Section 2 presents the literature review. Section 3 is focused on establishing and discussing the relationships of the SPM and SP Inventory Management with the SCN. The generic structure of the models and the specific models are presented in Section 4. Finally, Section 5 shows the conclusions and the final remarks of the paper.

2. LITERATURE REVIEW

The specificity of the SPs requires specific approaches to properly manage them. SPM must deal with peculiar characteristics, which makes it especially difficult. In general, the decisions considered on SPM should be addressed by integrating specific and different aspects (e.g., criticality, demand pattern, specificity, price, stock-out cost). Typically, the related literature on SPM has been focused on these aspects but addressing them separately. Even so, it is possible to find works that simultaneously consider different aspects of SPM trying to highlight the relationships between them (Huiskonen, 2001; Cavalieri et al., 2008; Boylan and Syntetos, 2010; Martin et al., 2010; Wagner et al., 2012; Roda et al., 2014; Driessen et al., 2015; Durán et al., 2016, Hu, et al., 2017). Moreover, some of these papers highlight the relevance of considering more holistic and multidisciplinary approaches as an opportunity to improve the SPM performance (Huiskonen, 2001; Martin, et al., 2010). Nevertheless, the related literature focuses mainly on single-location techniques instead of multi-location approaches that integrate these aspects.

The SPs classification is commonly used in real industrial cases, where criticality and demand pattern may be crucial elements to be considered. Outcomes of classification techniques are used to select the forecast techniques, the ICP and some related decisions (e.g., re-order points, order sizes, service levels), maintenance strategy, among others. Despite its strong relevance, classification is still an open discussion, and a wide variety of approaches and techniques can be found on the related literature (Braglia, et al., 2004; Roda, et al., 2014). The selection of a proper forecast technique is another important issue to be considered in this uncertain context. Indeed, the demand of several SPs is erratic and intermittent, making forecasting a very difficult task (Cavalieri et al., 2008; Boylan and Syntetos, 2010). The selection of the proper ICP to manage the SPs is a critical decision for SPM (Durán et al., 2016). Considering the demand nature, typical ICP models may not be suitable to manage SP inventories (Kennedy, et al., 2002; do Rego and De Mesquita, 2011; Driessen, et al., 2015; Bounou, et al., 2017).

More specifically, it is worth remarking that the demand pattern of the SPs is one of the characteristics that made these parts different from other materials and products. The intermittent nature of the demand pattern is a common feature in most of the SPs behaviors. Naturally, the unavailability of the SPs can lead to downtimes that generate strong consequences on the global performance (Cavalieri et al., 2008; Syntetos, et al., 2012; Roda et al., 2014). Then, inventories of SPs are required to ensure the availability of the system. In this context, the selection of a proper ICP turns to be especially relevant. Accordingly, this issue has received special attention in the literature. Most of the papers are focused on the application of inventory theory on the SPs specific contexts. The most common approach to select the ICP is driving it by the classification technique used to segregate the SPs. Consequently, it is possible to understand some of the relationships between the specific features of a SP class and the most suitable ICPs (Kennedy, et al., 2002; Braglia, et al., 2004; Cavalieri, et al., 2008; do Rego and De Mesquita, 2011; Bounou, et al., 2017).

On the other hand, SC is one of the main concerns for companies especially for the impact on global performance. Consequently, Supply Chain Management (SCM) became an important field of literature and in practice. SCM involves decisions related to the activities, processes, and resources required to be efficiently and timely managed (Simchi-Levi, et al., 2003; Coyle, et al., 2003). Particularly, the SCN design has a significant impact on the global performance (Miranda and Garrido, 2004; Shen, 2007; Melo et al., 2009; Farahani, et al., 2014). Applying the general knowledge of SCM over SPM, to accomplish the proposed goals, the company needs to coordinate the SP-SC considering all the involved activities. However, the SP-SC must not be only focused on the internal activities and processes, indeed this normally spans links with third parties (Huiskonen, 2001; Frazzon, et al., 2014). The SP-SCN has not been widely studied in the related literature. Most of the works that integrate SPs with SC are in fact focused on the processes across the SP-SC, but do not consider the relationships with the SP-SCN structure (Huiskonen, 2001; Rosseti and Thomas, 2006; Martin et al., 2010; Wagner, et al., 2012).

It is worth pointing out that most of the papers on SCM are focused on products (e.g., raw materials and finished products) considering the inbound and outbound logistics (Tracey, et al., 2005; Wu, et al., 2006; Tsao and Lu, 2012). On an SCN design context, one of the key decisions is facility location. Consequently, Facility Location Problems (FLPs) have been widely studied in the literature. Naturally, strategic decisions related to FLPs impact on the long-term horizon (Coyle et al., 2003; Snyder, 2006). Mainly based on FLPs, Inventory Location Problems (ILPs) typically integrate the location of facilities, customer assignment, and inventory control decisions. This integration should lead to better solutions, but it incorporates complexity on the mathematical models (Jayaraman, 1998; Farahani, et al., 2015). Transferring this general knowledge to SPM is worth as research particularly due to extant gaps.

3. SPARE PARTS SUPPLY CHAIN

According to Simchi-Levi et al. (2003), SC is a system consisting of suppliers, manufacturers, transportation, distributors, and vendors that exists to transform raw materials to final products and supply those products to customers. SCM is focused on the efficient integration of SC's components to produce and distribute right quantities to the right locations at the right time. This should be made minimizing the total system costs and satisfying customers' requirements.

According to Harland et al. (2001), both SC and SCN describe the flows (i.e., materials and information) between the diverse components, but SCN describes a more complex structure (see Fig. 1). In general, SC describes a simpler and sequential set of links, SCN considers where organizations can be cross-linked, and there are two-way exchanges between them.

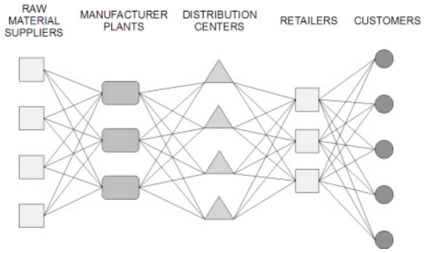

Fig. 1. A Generic Supply Chain Network

On the other hand, SPM spans all the decisions from the purchase to the use or consumption of the SPs. Consequently, these decisions consider procurement, inventories, logistics, and supply chain. One of the main issues for the SPM is to minimize the unexpected downtimes supplying the required SPs at the right place and time. Consequently, to properly respond to this issue the decisions cannot be made in isolation and it is required to consider the impact of each aspect on the other decisions (Huiskonen, 2001; Martin et al., 2010; Wagner et al., 2012; Driessen et al., 2015).

According to these definitions, SC can be considered as a relevant part of SPM for ensuring efficiency and continuity of productive activities. Moreover, in the other side, SCM perspective and approaches are quite proper to enable SPM purposes. However, only a few studies go further in this analysis (Huiskonen, 2001; Wagner, et al., 2002; Martin, et al., 2010). With this aim, the focus of this paper is understanding and studying the SP-SC, and the related network design problems. Therefore, according to the previous discussion about SPs peculiarities in Section 2, it is expected that due to the specific characteristics and behaviors of the SP, different SCN structures will fit better for different SP classes. Huiskonen (2001) highlights the relevance of the inventory location from a logistic perspective. Wagner et al., (2002) gives a similar discussion distinguishing between central and local inventories based on the SP characteristics. In general, it is assessed in the literature that different classes of SPs can be identified within a company based on multiple-criteria (e.g., like price, lead time, stock-out cost and specificity) and depending on the criticality of the class they should be managed differently (Roda et al. 2014).

Considering that different SCN structures may fit better with different SP characteristics, it is worth to consider the availability of network optimization modeling structures that enable to cope with different needs of the variety of SPs classes. Fig. 2 presents a generic SP-SCN, considering SPs' suppliers, internal warehouses, and consumption points. Internal warehouses are the set of facilities located to serve the demand generated from inventories. In general, a consumption point can be defined as a production activity that consumes SPs for replacements purposes. This structure is derived from the related literature that addresses some SP-SCN issues (Huiskonen, 2001; Martin, et al., 2010), but also considering the structure assumed by the proposed models.

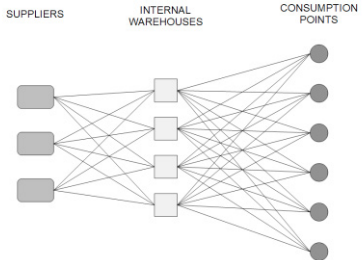

Fig. 2. A Generic Spare Parts Supply Chain Network

4. OPTIMIZATION MODELS FOR SP-SCN

This section is focused on presenting a generic single-commodity model based on a joint warehouse location and inventory control modeling structure to optimize the SP-SCN. Additionally, three models, derived from the generic model, considering three different ICPs are presented.

4.1 Generic Modeling Structure

The proposed generic model considers a common structure based on a typical FLP. It is assumed that the supplier is fixed and known. Additionally, the generic model considers as known and fixed the same ICP for each warehouse. This model is focused on jointly optimizing the warehouse locations, the consumption points' assignment and the inventory control decision. The located warehouses will storage the SP inventories. These inventories will be used to serve the demands generated at each consumption point assigned to each warehouse. Inventory control decisions are related to sizing the inventory level for each warehouse. The demand that each warehouse faces is obtained as a function of the demand of each assigned consumption point. The consumption points' demand is characterized by its mean and variance. Finally, the models aim to minimize the total cost function of the network. The SCN decision variables are:

X_i	Binary variable. It values 1 if a warehouse is located on site *i*, 0 otherwise.
Y_{ij}	Binary variable. It values 1 if the consumption point *j* is assigned to the warehouse *i*, 0 otherwise
D_i	Demand mean served by the warehouse *i*
V_i	Variance of the demand served by the warehouse *i*

The parameters and the sets are the following:

FC_i	Setting and operational fixed cost of a warehouse on location *i*
CIn_i	Inbound transportation cost of a warehouse on the location *i* (from a known source or spare parts provider)
$COut_{ij}$	Outbound transportation cost of a warehouse on location *i* for serving user *j*
μ_j	Mean of the spare part demand of the

	consumption point j
σ_j	Variance of the spare part demand of the consumption point j
$TC\text{-}ICP_i^p$	Total cost associated with the Inventory Control Policy type p for the warehouse on location I, depending on mean and variance of demand served by the warehouse.
N	Set of potential warehouses
M	Set of consumption points (i.e. the assets operating in the industrial plant at the end-user site)

Then, the generic model structure is as follows:

$$\begin{aligned} Min \quad & \sum_{i\in N} FC_i \cdot X_i + \sum_{i\in N}\sum_{j\in M}\left(CIn_i + COut_{ij}\right)\cdot \mu_j \cdot Y_{ij} \\ & + \sum_{i\in N} TC\text{-}ICP_i^p\left(D(X,Y),V(X,Y)\right) \end{aligned} \tag{1}$$

s.t.:

$$\sum_{i\in N} Y_{ij} = 1 \qquad \forall j \in M \tag{2}$$

$$Y_{ij} \le X_i \qquad \forall i \in N, \forall j \in M \tag{3}$$

$$D_i = \sum_{j=1}^{M} Y_{ij} \cdot \mu_j \qquad \forall i \in N \tag{4}$$

$$V_i = \sum_{j=1}^{M} Y_{ij} \cdot \sigma_j \qquad \forall i \in N \tag{5}$$

$$X_i, Y_{ij} \in \{0,1\} \qquad \forall i \in N, \forall j \in M \tag{6}$$

Expression (1) represents the objective function that corresponds to the total SCN costs. The first term represents the setting and operating fixed costs for all warehouses. The second term is the total transportation costs (provider – warehouses and warehouses – end-users). The third term represents the total costs related to the ICP at each warehouse. Equations (2) ensure that each consumption point must be served by a single warehouse. Constraints (3) ensure that the users are assigned only to installed warehouses. Equations (4) and (5) compute demand mean and variance that must be served by each warehouse. Equations (6) represent the binary domain of the SCN decision variables.

4.2 Specific Models

To adapt the generic model to the specific needs of a variety of SP classes, this paper also presents three specific formulations derived from the basic model structure by considering specific ICPs. For each specific formulation, it is required to define additional parameters and decisions variables. It is required to be mentioned that a Normal approximation is assumed to model demands at the consumption points and warehouses. The additional parameters are:

OC_i	Fixed ordering cost for the warehouse in the location i
HC_i	Unitary holding at a warehouse in the location i
LT_i	Lead time for an incoming order to the warehouse in the location i
α	Minimum required stock-out probability at each warehouse
$Z_{1-\alpha}$	Standard normal distribution value that accumulates $1-\alpha$

The specific main decision and auxiliary decision variables are as follows:

Q_i	Order quantity for the warehouse i
U_i	Undershoot at the warehouse i
S_i	Maximum objective inventory level for the warehouse i
s_i	Re-order point for the warehouse i

Notice that these variables are not considered for all the models. The variables that are considered on each specific model depend on the employed ICP.

Additionally, just as considered in most of the traditional inventory and SPM literature, when an order is submitted the inventory level should cover the demand generated during the lead time with a probability $(1 - \alpha)$. This probability is known as the inventory service level, and α is defined as the stock out probability.

a) Continuous Review (s, Q)

The first model considers a continuous review with a fixed order quantity policy (Q). The re-order point s defines the inventory position when a replenishment order must take place. When the inventory level reaches the re-order point, an order of size Q is submitted. This order arrives after the lead time. In this case, the total cost of the ICP for each warehouse can be expressed as follows:

$$\begin{aligned} & TC\text{-}ICP_i^a\left(D(X,Y),V(X,Y)\right) \\ & = \left(\frac{OC_i \cdot D_i}{Q_i} + \frac{HC_i \cdot Q_i}{2}\right) + HC_i \cdot Z_{1-\alpha} \cdot \sqrt{LT_i} \cdot \sqrt{V_i} \end{aligned} \tag{1a}$$

The first term represents the ordering costs and holding costs of cycle inventory. The second term represents the safety stock cost.

b) Periodic Review (R, s, S)

The second specific model considers a periodic review with a variable order quantity policy. In this policy, the stock level is reviewed at the end of a fixed period of R units of time. If there are less or equal units than the re-order point (s) a replenishment order is submitted. The size of the order is aimed to return the stock level to the maximum objective stock level (S). Accordingly, the order size is variable and depends on the inventory level $I(t)$. If an order must be submitted, the difference between re-order point and the inventory level is known as undershoot (U). The average undershoot, as a function of demand mean and variance of warehouse i, D_i and V_i, and for a review period R_i, can be computed as showed in (7).

For this ICP, (1) can be expressed is as follows:

$$\begin{aligned} & TC\text{-}ICP_i^b\left(D(X,Y),V(X,Y)\right) \\ & = \left(\frac{OC_i \cdot D_i}{\left(Q_i + U_i\right)} + \frac{HC_i \cdot \left(Q_i + U_i\right)}{2}\right) \\ & \quad + HC_i\left(D_i \cdot R_i + Z_{1-\alpha} \cdot \sqrt{LT_i + R_i} \cdot \sqrt{V_i} - U_i\right) \end{aligned} \tag{1b}$$

The first term represents the ordering cost and holding cost of cycle for a variable lot size ($Q_i + U_i$), where Q_i is computed as the Economic Order Quantity. The third term represents the safety stock cost.

$$U_i = \frac{V_i}{2 \cdot D_i} + \frac{D_i \cdot R_i}{2} \qquad \forall i = 1,...,N \qquad (7)$$

c) Continuous Review (S-1, S)

The third specific model considers a continuous review ICP known as "one for one replenishment policy". Whenever a demand arises, a replenishment order is submitted. The order size depends on the number of units consumed. Nevertheless, the demand for an SP may behave as a one by one demand process. In this case, (1) is expressed as follows:

$$\begin{aligned} &TC\text{-}ICP_i^c\left(D\left(X,Y\right),V\left(X,Y\right)\right) \\ &= OC_i \cdot D_i + HC_i \cdot \left(S_i - D_i \cdot LT_i\right) \end{aligned} \qquad (1c)$$

The first term considers the ordering cost that it is assumed each time that a demand arises. The second term represents the holding cost.

4.3 Concluding Remarks

It is now worth to summarize the main aspects involved in this paper. To this end, it is crucial to highlight the relationships between the SPM process, the SP-SCN and the ILPs, addressed in this paper.

First, it is worth to point out that this paper is based on two foci: i) the impact of related decisions involved into the SPM process and ii) the fact that the integration of decisions makes possible the improvement of SP-SC performance. The first focus is closely related to the hierarchical and sequential structure used to make related decisions; this is also an approach that is well understood in managerial practice. The second focus is, instead, obtained based on a more mathematical perspective, where the optimization models that integrate decisions may enable finding better solutions to improve practice. Therefore, having a synergic view of the two foci, this paper leads to include the SCN design issues into the SPM process, thus relating decisions, and to present a generic structure that integrates SCN and inventory decisions, thus creating the potentials for SCM improvement. Overall, this modeling structure can be classified as an ILP model, which then may become mean to bring the SCN design into the SCM process.

The proposal has potential managerial implications and interest for the decision makers. From the SP manager's perspective, this paper shows a structured approach to integrate decisions involved in the SPM process. Moreover, this work is also aimed to generate a direct link between the SP managers and the SCN managers, helping to coordinate, collaborate and improve the SP-SC performance. Such integrated decision-making could be put in practice within a company, after proper data gathering and analysis (e.g. mean and variance of the demand at the spare parts consumption point, etc.).

5. CONCLUSIONS AND FUTURE RESEARCH

SPs and SPM are well-known issues in decisional problems in industrial practice and, when looking for cost-effective management, they have become relevant to companies, especially in equipment-intensive industries. The related literature has been focused on the specific characteristics and behaviors of SPs and the management subsequently needed. Most of these papers are focused on such specific characteristics considering, in limited scopes, the impact that a decision may have over other decisions. Among them, the SC, SCM and SCN issues have been excluded from most of the SPM literature concerned with an end-user perspective (i.e., the owner of the assets in industrial sites). Some authors reflect on the relevance of more integrated approaches to improve the SPM process performance. Then, the integration of different decisions involved in the SPM process may be crucial to improve the global performance, so also the cost-effectiveness.

Having in mind such purpose of integrated decisions, this paper proposes a generic modeling structure integrating SPs warehouse location and inventory control decisions. This model assumes the general structure of the FLPs, where the consumption points must be assigned to a warehouse to be served of SPs. An ICP is then assumed for all the potential warehouses and it is dependent on the SCN structure, particularly on the consumption points' assignments. The demand processes are modeled assuming a Normal approximation. Consequently, the consumption points' demand is represented by the mean and the variance. A generic expression for the cost function is then shown. This cost function depends on the specific ICP and the SCN structure variables (*X* and *Y*). Based on the generic model, three specific ICPs were also considered to derive three specific models. These ICPs were selected because they are widely used according to the variety of features of SPs. It is then remarkable that the generic model is now adapted to different SPs classes. Indeed, in the mathematical model, each specific model shows the cost function for the specific ICP depending on the SCN structure variables.

For the future, it is possible to include different constraints, decisions, and features to make the models more applicable in real-world cases (e.g., capacity constraints, supplier selection decisions, lateral transshipment, multi-commodity, and multi-period). It is also possible to develop new specific models considering other suitable ICPs. Furthermore, due to the structure of the generic and specific models, it is possible to focus on the development of a generic solution algorithm structure, or engineering methodology, to solve and make applicable the models in real-world cases. Future research may also test the impact on the SPM performances by using different ICPs (i.e. specific models) for different SPs' classes.

ACKNOWLEDGMENT

This research work was performed within the context of SustainOwner ("Sustainable Design and Management of Industrial Assets through Total Value and Cost of Ownership"), a project sponsored by the EU Framework Programme Horizon 2020, MSCA-RISE-2014: Marie

Skłodowska-Curie Research and Innovation Staff Exchange (RISE), grant agreement number 645733-Sustain-Owner-H2020-MSCA-RISE-2014.

REFERENCES

Bounou, O., El Barkany, A., El Biyaali, A. (2017). Inventory Models for Spare Parts Management: A Review. International Journal of Engineering Research in Africa, 28, 182-198.

Boylan, J.E., Syntetos, A.A. (2010). Spare parts management: a review of forecasting research and extensions. IMA Journal of Management Mathematics, 21, 227-237.

Cavalieri, S., Garreti, M., Macchi, M., Pinto, R. (2008). A decision-making framework for managing maintenance spare parts. Production Planning & Control, 19(4), 379-396.

Coyle, J.J., Bardi, E.J., Langley, C.J. (2003). The Management of Business Logistics: A Supply Chain Perspective. Quebec: Transcontinental Louisville.

Daskin M.S., Coullard C.R., Max Shen Z.J. (2002). An Inventory-location Model: Formulation, Solution Algorithm and Computational Results. Annals of Operations Research, 110(1), 83-106.

Driessen, M., Arts, J., van Houtum, G.J., Rustemburg, J.W., Huisman, B. (2015). Maintenance spare parts planning and control: a framework for control and agenda for future research. Production Planning and Control, 26(5), 407-426.

Do Rego, J.R., De Mesquita, M.A. (2011). Spare parts inventory control: a literatura review, Producao, 21(4), 645-655.

Durán, O., Roda, I., Macchi, M. (2016). Linking the Spare Parts Management with the Total Cost of Ownership: An Agenda for Future Research. Journal of Industrial Engineering and Management, 9(5), 991-1002.

Erlebacher, S.J., Meller, R.D. (2000). The interaction of location and inventory in designing distribution systems. IIE Transactions, 32(2), 155-166.

Farahani, R.Z., Rashidi Bajgan, H., Fahimnia, B. Kaviani, M. (2015). Location-inventory problem in supply chains: a modeling review. International Journal of Production Research, 53(12), 3769 – 3788.

Farahani, R.Z., Rezapour, S., Drezner, T., Fallah, S. (2014). Competitive supply chain network design: An overview of classifications, models, solution techniques and applications. Omega, 45, 92 – 118.

Frazzon, E.M., Israel, E., Albrecht, A., Pereira, C.E., Hellingrath, B. (2014). Spare parts supply chains' operational planning using technical condition information from intelligent maintenance systems. Annual Reviews in Control, 38, 147-154.

Harland, C.M., Lamming, R.C., Zheng, J., Johnsen, T.E. (2001). A Taxonomy of Supply Networks. Journal of Supply Chain Management, 37(3), 21-27.

Hu, Q., Boylan, J.E., Chen, H., Labib, A. (2017). OR in spare parts management: A review. European Journal of Operational Research, Article in Press, 2017, doi: 10.1016/j.ejor.2017.07.058.

Huiskonen, J. (2001). Maintenance spare parts logistics: Special characteristics and strategic choices. International Journal of Productions Economics, 71, 125-133.

Jayaraman, V. (1998). Transportation, facility location and inventory issues in distribution network design: An investigation. International Journal of Operations and Production Management, 18(5), 471 – 494

Kennedy, W.J., Patterson, J.W., Fredendall, L.D. (2002) International Journal of Production Economics, 76, 201-215.

Martin, H., Syntetos, A.A., Parodi, A., Polychronakis, Y.E., Pintelon, L. (2010). Integrating the spare parts supply chain: an inter-disciplinary account. Journal of Manufacturing Technology Management, 21(2), 2010, 226-245.

Melo, M.T., Nickel, S., Saldanha-da-Gama, F. (2009). Facility location and supply chain management – A review. European Journal of Operational Research, 196, 401 – 412.

Miranda, P.A., Garrido, R.A. (2004). Incorporating inventory control decisions into a strategic distribution network design model with stochastic demand. Transportation Research Part E: Logistics and Transportation Review, 40(3), 183 – 207.

Roda, I., Macchi, M., Fumagalli, L., Viveros, P. (2014). A review of multi-criteria classification of spare parts: From literature analysis to industrial evidences. Journal of Manufacturing Technology Management, 25(4), 528-549.

Rosseti, M.D., Thomas, S. (2006). Object-Oriented Multi-Indenture Multi-Echelon Spare Parts Supply Chain Simulation Model. International Journal of Modelling and Simulation, 26(4), 359-369.

Shen, Z.J. (2007). Integrated Supply Chain Design Models: A Survey and Future Research Directions. Journal of Industrial and Management Optimization, 3(1), 1 – 27.

Simchi-Levi, D., Kaminsky, P., Simchi-Levi, E. (2003). Designing and Managing the Supply Chain: Concepts, Strategies and Case Studies. New York, NY: McGraw-Hill.

Snyder, L. (2006). Facility location under uncertainty: a review. IIE Transactions, 38, 537 – 554.

Syntetos, A.A., Babai, M.Z., Altay, N. (2012). On the demand distribution of spare parts. International Journal of Production Research, 50(8), 2101-2117.

Tracey, M., Lim, J.-S. Vonderembse, M.A. (2005). The impact of supply-chain management capabilities on business performance. Supply Chain Management, 10(3), 179-191.

Tsao, Y.,-C., Lu, J,-C. (2012). A supply chain network design considering transportation cost discounts. Transportation Research Part E: Logistics and Transportation Review, 48(2), 401-414.

Wagner, S.M., Jönke, R., Eisingerich, A.B. (2012). A Strategic Framework for Spare Parts Logistics. California Management Review, 54(4), 69-92.

Wu, T., Blackhurst, J., Chidambaram, V. (2006). A model for inbound supply risk analysis. Computers in Industry, 57(4), 350-365.