Estimating the distribution cost in Large-Scale Retail Trade companies from network configuration

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Abstract: Distribution processes account for a large stake of direct costs in Large-Scale Retail Trade (LSRT) companies and here, more than in other industries, the quest for efficiency is critical to defend the low operating margins. Because here distribution networks endlessly vary, following the continuous opening and closing of stores, the company management needs synthetical metrics to estimate the transportation cost resulting from a hypothetic distribution configuration. The two data types that are always available to the logistic manager in a LSRT company are the stores' addresses and their expected turnover. The aim of this paper is proposing a methodology for a synthetic estimation of the distribution cost related to a given distribution network, only leveraging on these data. This would allow LSTR companies to easily evaluate the impact of distribution decisions on transportation cost without recurring to complex and often impracticable simulative approaches. The methodology exploits a set of functions relating store locations, turnovers, distribution routes, mileages, fares and transportation costs. These functions have been calibrated upon the case of a LSRT company operating in south-east Italy and, subsequently, validated onto the case study of a different company in north Italy. The methodology has demonstrated to be satisfactorily generic to yield correct results also on very dissimilar industrial cases, showing the potentiality to support decision-making in distribution management for LSRT companies.

Keywords: Large-Scale Retail Trade; Distribution; Logistics; Routes.

1. Introduction

Large-Scale Retail Trade (LSRT) can be defined as the set of operations aimed at providing variable quantities of a considerable variety of goods to a large number of consumers, through the implementation of complex and multifaceted distribution channels. This industry represents an important pillar of the modern world, and its role directly reflects on the high standards and service levels required to companies that operate in this domain.

The LSRT sector is generally characterized by large turnovers and low operating margins, since many variables significantly impact on the companies' direct and indirect costs (Lucci, et al., 2018). Choices regarding these critical factors (e.g. purchasing, distribution, routing) are essential to determine the performances of a LSRT company and should be made with caution. However, following the dynamics of LSRT companies and their network configurations, these parameters systematically vary and compel the companies' management to choose quickly and effectively for achieving great competitive results. Therefore, managers need adequate tools to evaluate and predict their influence on the company results, providing a valid support to the decision-making process.

Among the critical elements, a large portion of LSRT companies' direct costs originate from distribution processes. The distribution activities entail selling and delivering to the customer the requested products at the right moment from one or more Distribution Centres (DCs), whose positioning is a critical choice to minimize the overall logistics costs (Di Pietro, et al., 2019). This decision mainly depends on the specific network configuration, which is represented by the stores to be served, and on the stores' turnover, that defines the quantity of goods to be distributed. However, both elements – network configuration and stores' turnover – are often subject to variations, leading in turn to variations in terms of transportation costs. Hence, when making decisions related to the distribution configuration, the company management needs synthetical metrics to estimate the resultant transportation costs.

Several authors have outlined the significant role and impact of transportation costs on the distribution processes (Di Pietro, et al., 2019; Janne, et al., 2012), even though it seems that no evidence is present in relation to a synthetic estimation. Indeed, the transportation costs estimation carries on with several complexities, either linked to the unavailability of data or to the considerable effort required to pursue simulation approaches. The eventual investment in expensive Transportation Management System (TMS) software may be ineffective when an ex-ante evaluation of different scenarios is needed. The two data types that are always available to the logistic manager in a LSRT company, also when what-if analysis is to be performed, are the stores' addresses and their expected turnover; hence, the aim of this paper is to propose a methodology to evaluate the resultant transportation costs from a specific distribution configuration, only drawing up from information on stores' addresses and expected turnover. Indeed, through this approach managers will be able to obtain a simple yet effective indication on the results of their decisions.

Using the proposed methodology, a relationship between the stores' distances from the distribution centre (DC) and the total covered distance of a route has been established. This relationship has been calibrated onto the case of a LSRT company operating in south-east of Italy, leveraging on the precise data recorded through a TMS software in use since some years. Then, the methodology has been applied and validated onto the case study of a second company in north Italy, which differently does not have a TMS software yet. Note that even though the considered companies show dissimilarities in terms of distribution configuration and turnovers, these differences have been appropriately taken into account through specific parameters, and allowed to assess the effectiveness of the proposed methodology.

The paper is therefore divided into two main parts. In the first part, a literature review of the scientific contributions related to distribution processes in LSRT companies is presented. The second part of the paper describes the methodology for estimating the distribution cost and, after defining the companies' specific distribution configuration, validates it on the case study of a large LSRT Italian company.

2. Literature Review

The relevance of logistics costs has been widely assessed in the present literature. These costs represent one of the most important parameters for measuring LSRT performances and their reduction is regularly a company objective. Several efforts have been made to determine the main elements characterizing the logistics costs. Indeed, Zeng and Rossetti (2003) provide a six-items classification for the logistics costs – transportation, inventory holding, administration, customs, risk and damage, handling and packaging – which has been adopted by many authors. Differently, Bokor (2010) identifies the most relevant logistics and transportation cost drivers through the application of AHP methodology.

Considering the classification provided by Zeng and Rossetti (2003), transportation is the largest cost among the different categories. Indeed, Tseng et al. (2005) highlight that “transportation occupies one-third of the amount in the logistics costs and transportation systems influence the performance of logistics system hugely”, while Parkhi et al. (2014) state that transportation costs compose on average fifty percent of logistics costs. Therefore, great attention is paid to logistics costs optimization, and specifically to distribution costs optimization. Lucci et. al (2018) define that transportation costs optimization in LSRT industry is generally addressed by following three different approaches: distribution network design (Lin & Wang, 2018; Meidutė, 2007), routing optimization (Grob, et al., 2019; Ehmke, et al., 2018), distribution planning (Minken & Johansen, 2019; Sainathuni, et al., 2014).

Even though these approaches seem to be far from each other, they are linked by a thin thread: the decision-making process. Indeed, in order to obtain competitive advantage and to reduce the distribution costs, the efforts made for streamlining the logistics operations ought to be supported by an efficient and effective decision-making. The importance of an efficient decision-making has been pointed out by different authors, such as Bokor (2008) and Caplice and Steffi (1995). In this context, Stepien et al. (2016) study the dependencies between the several logistics costs categories and the management efficiency, concluding that having useful information on the company's performances could allow a quick decision-making and improve its effectiveness. Indeed, managers – especially in the LSRT industry, where rapid responses are crucial to defend the company's low operating margins – need simple tools and methodologies to make effective decisions in a short time.

Within the extant literature, some contributions have been made to perform the estimation of total logistics costs, whereas to the authors' knowledge no attempt is made to determine a perspective evaluation of transportation costs resulting from strategic decisions. For instance, Bowersox et al. (2003) provide a methodology for estimating global logistics expenditures through neural networks algorithms. Despite the method shows good results in evaluating the total logistics costs, it does not focus explicitly on transportation costs and requires a great technical knowledge, which is seldom owned by industrial managers. The same issue can be found in the contribution of Creazza et al. (2010), that provides a methodology for evaluating logistics costs in some specific network configurations, where shipments occur from the supplier to the regional warehouses. Moreover, the abovementioned paper does not take into consideration the last tier of the supply chain, namely distribution from warehouses to the final customers. Differently from the previous authors, Janne et al. (2012) try to measure logistics costs adopting a survey-based approach, and specifically through a Generalised Linear Mixed Model (GLMM) method. However, they estimate logistics costs considering only turnover and company internationalization as explanatory variables, without taking into account the stores' location. The latter represents a major assumption for the LSRT industry, since the stores' location heavily influence the distribution costs (Hesse & Rodrigue, 2004), and thus the model seems inapplicable to the specific industry.

To sum up, great effort has been made in the literature for optimizing the whole supply chain for the LSRT industry, and several models have been developed for the various instances. Along with this, managers need simple and effective tools and methodologies for performing an efficient decision-making, especially when considering strategic decisions (e.g. stores' opening/closure, opening/closure of distribution centres, etc.). Indeed, without an effective decision-making process, all the efforts for streamlining the operations could be vain. To our knowledge, few authors proposed a model to simply evaluate the logistics costs of a company starting from practically available data and without invoking complex – mostly inapplicable – mathematical approaches. Indeed, these models result unsuitable for LSRT industry also for their specific assumptions, beyond for the great complexity of the proposed techniques. Furthermore, there is no evidence of contributions useful to support what-if analyses related to the eventual distribution configurations of a LSRT company. Hence, this paper aims at filling the present gap in the literature through the proposal of a simple method for estimating the distribution costs of a LSRT company, also allowing what-if analyses and supporting the decision-making process.

3. Methodology for estimating the distribution costs

Distribution costs in LSRT industry significantly depend on the total travelled distance, which in turn depends on the goods flow between the DCs and the served stores. For this reason, when evaluating the distribution costs of a LSRT company – and especially when the transportation fares are defined by a variable cost per km – the total travelled distance can be considered as a proxy for the estimation (Bokor, 2010). Therefore, the methodology has the objective to estimate the distribution costs of a LSRT company, only leveraging on stores' addresses and their expected turnover. Indeed, these two types of data are always available to a LSRT manager and should be used for performing perspective analyses related to the company's distribution configuration.

In light of the previous considerations, to obtain an overall estimation of the total travelled distance of a LSRT company, it is possible to correlate the total travelled distance of a route with the sum of distances from the DC of the stores served by that route, per number of served stores. Indeed, the definition of a relationship between the abovementioned parameters (i.e. travelled distance in a route; served stores' sum of distances from the DC) allows to obtain an indication of the overall distance to be covered in a distribution route, only knowing the number of stores to be served and their addresses. Hence, considering a distribution fare defined in €/km and the total number of distribution routes, the estimation of the distribution costs is straightforward.

The proposed methodology is a 5-steps procedure that considers a set of functions which have been calibrated upon the case of a training company and subsequently validated upon the case study of a test company. Hence, the methodology is given as follows:

1. descriptive analysis of the companies' distribution configuration;
2. regression analysis on the training company's data, in order to determine the relationship between the total travelled distance in a route and the served stores' sum of distances from the DC. Note that these calculations can be performed since the training company already implemented a TMS software, hence the large availability of distribution routes' data;
3. individuation of coefficients to consider the different distribution configurations of the companies. This step is relevant since, in order to estimate the distribution costs of the test company, transfer functions are necessary to effectively compare the stores' distances and turnovers of the training and test company;
4. calculation of the average number of served stores in a distribution route and average number of distribution routes in the considered time horizon for the test company, using distribution coefficients obtained in *step 3*. Note that this computation must be performed since the test company did not implement a TMS software yet and there is no available distribution data;
5. estimation of the test company's total travelled distance, using the linear relationships and the parameters obtained respectively in *step 2* and *step 4*. Furthermore, adopting a specific distribution fare, it is possible to provide an estimate of the test company's distribution costs. This step also allows to analyze the effectiveness of the methodology – in terms of estimation error – and to draw up some distribution considerations.

Hence, this methodology leads to compute the total travelled distance for distribution routes and, in turn, the distribution costs, only based on the store addresses and turnovers and without the need of any specific software. Note that this paper provides the linear relationships for estimating the total travelled distance and the transfer functions for comparing different distribution configurations (i.e. *step 2* and *step 3*), and successively applies the identified relationships and functions to a specific case study. It is possible to observe that further applications of this procedure to other industrial cases can be narrowed down only to *step 4* and *step 5*, adopting the relationships provided by this contribution and following the approach of the proposed case study. Moreover, since the method aims at estimating the overall distribution cost adopting the travelled distance as a proxy, any particular tendency (e.g. seasonality, trends) are directly incorporated within the estimation. Hence, no further calculations or analyses are required for performing this estimate.

3.1 Description of the LSRT companies' network configurations

The proposed method relates several different variables comprising store locations, turnovers, distribution routes, mileages and fares to estimate the company transportation costs. The relationships among these variables have been calibrated using data of a large LSRT Italian company, operating in the southern part of the Italian territory with 296 stores. The company distributes more than 14'000 SKUs and operates with only one distribution centre (DC) and with a "Cash&Carry" (CC), both located in south-east of Italy. This company has been chosen as the "training company", due to the large amount of data available on the company's TMS system. Note that this company is referred as the training company since its data allowed to build the relationships among the identified variables and – consequently – the proposed methodology. Subsequently, the method has been applied and validated onto the case of a second large LSRT Italian company, distributing more than 18'000 SKUs and operating in the northern part of the Italian territory with 525 stores. This case study allowed to

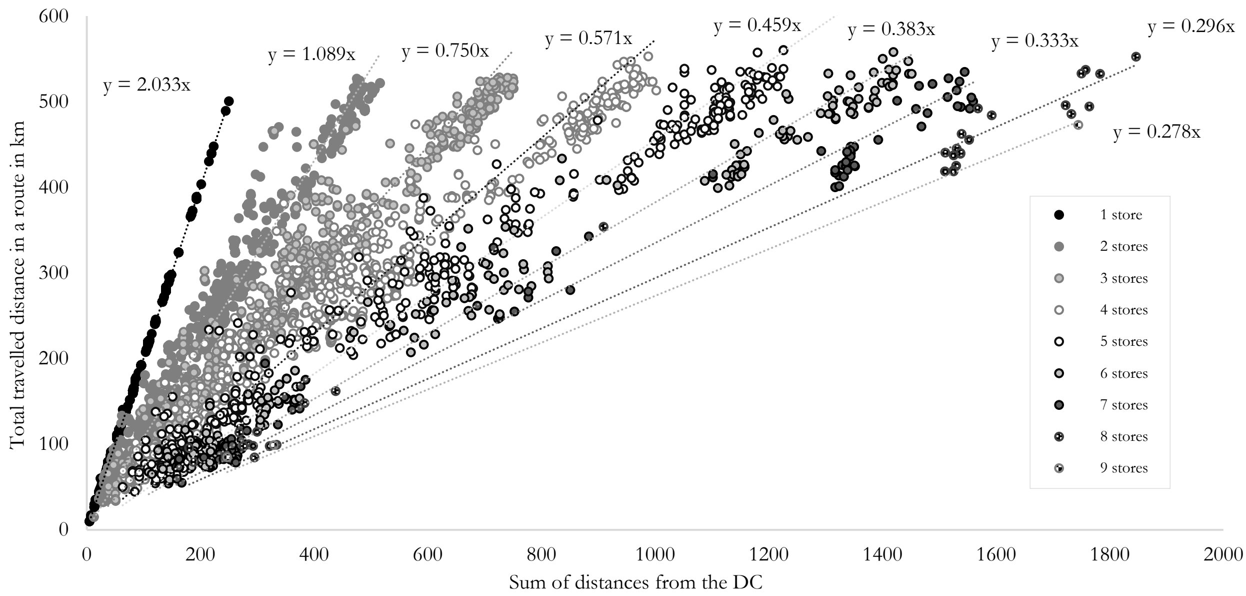

Figure 1: regression analysis of the travelled distance in a route and the stores' sum of distances from the DC, per number of served stores

test and validate the identified mathematical relationships; hence, the considered company is referred as the "test company". Differently from the training company, the test company did not use any TMS software for performing the distribution activities, thus the only available data were the stores' addresses and their turnover. However, these data resulted sufficient to estimating the distribution costs of the LSRT company.

The distribution of stores' distances from the DC for both training and test company is provided by Figure 1. Considering the training company, its distance distribution has a positive kurtosis and is left-skewed, showing that many stores are very close to the DC. The distance distribution of the test company is also left-skewed, but it shows a negative kurtosis since it is more even than the previous one. The latter effect on the distribution can be due to the wider territory served by the test company. Moreover, the distributions confirm the evidence that LSRT companies try to minimize the transportation costs: these costs are heavily influenced by stores' distance from the DC. As it has been already described, in what follows coefficients are calculated to take into account the different distribution configurations of the companies, both in terms of network topology and store sizes.

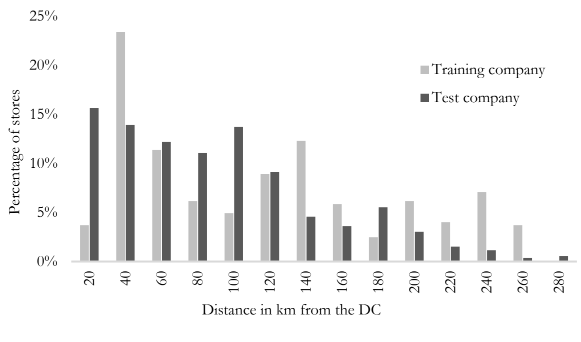

Figure 2: stores' distance distribution from the DC

3.2 Regression analysis

The training company dataset consists of 5'673 routes occurred from 01/02/2019 to 14/05/2019, with the following data for each route:

- Route number, date, served stores;
- Total travelled distance in km;
- Total cost of the route;
- Number of shipped pallets.

Moreover, considering the stores' addresses it has been possible to calculate the sum of distances from the DC to the served stores (i.e. the sum of the point-to-point road distances from the distribution center to stores that have been served in a specific distribution route – for instance, if a vehicle serves customer 1 and customer 2 in a distribution route, whose distances from the DC are respectively of 50 and 43 km, the sum of distances will be 93 km). Hence, the observations have been classified in relation to the number of served stores per route, and a simple linear regression analysis has been performed per each defined class. The results of the regression analyses are reported in Figure 2 and in Table 1, showing that the larger the number of served stores in a route, the smaller the magnitude of the slope. This means that when the number of served stores in a route increases, then the total travelled distance becomes much smaller than the stores' distances from the distribution centre.

According to the results, it is possible to observe that both the F-test significance and the P-value show values much lower than 0.05 whether the number of observations is large or small, hence the relationships can be considered reliable. Moreover, approximately 95% of the standardized residuals lie within the interval (-2,+2) for all the regressions, hence it can be supposed that the residuals are normally distributed and that the simple linear regression model is adequate (Montgomery & Runger, 2014).

Number of stores	Number of observations	Slope	R^2	F-test significance	P-value (t-statistics)
1	885	2.033	0.9998	0	0
2	1890	1.089	0.9917	0	0
3	1236	0.750	0.9866	0	0
4	738	0.571	0.9820	0	0
5	502	0.459	0.9899	0	0
6	227	0.383	0.9929	2.10E-241	2.92E-242
7	155	0.333	0.9941	2.71E-110	3.38E-111
8	34	0.296	0.9950	1.87E-37	2.13E-38
9	5	0.278	0.9996	2.05E-06	5.44E-08

Table 1: results of the regression analysis

3.3 Identification of coefficients related to network topology and stores' size

In order to estimate the total travelled distance of the test company through the identified linear relationships, coefficients should be identified to account for the company's specific distribution configuration. Indeed, the training and test companies perform the distribution activities adopting different configurations, both in terms of total travelled distance and transportation fares. However, while fares dissimilarities can be taken into account simply adopting the company's specific variable cost among the total cost computation, distance dissimilarities require a further deepening. For this reason, the proposed methodology introduces two coefficients to use the identified linear regressions, even when dissimilarities in the considered distribution configurations are acknowledged. Hence, this procedure allows the comparison of different datasets and to obtain unbiased estimates of the total distribution cost of a LSRT company.

Starting from the training company dataset, it is possible to determine two transfer functions to estimate the average number of served stores in a distribution route and the average number of distribution routes in the considered time horizon for the test company. The transfer functions are given as follows:

- Figure 3 shows the relationship between the average distance expressed in km of the store from the DC and the number of stores per route, which appears to be a logarithmic function. In addition, re-arranging the relationship it is possible to obtain the transfer function, which will be used to estimate the average number of served stores per route for the company i ($ASSR_i$). Note that the transfer function considers only the average distance of the stores from the DC ($ADDC_i$). Hence, the expression is given as follows

$$ASSR_i = e^{\frac{(ADDC_i - 62.6)}{30}} \quad (1)$$

where $ADDC_i \geq 62.6$, while in the other cases ($0 < ADDC_i < 62.6$) the average number of served stores per route is expected to be equal to 1 store/route.

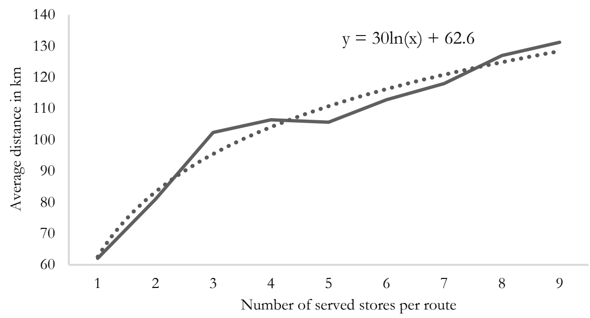

Figure 3: average distance from the DC, per number of served stores

It is possible to observe that from (1), the greater the average distance of the stores from the DC, the higher the average number of served stores per route. This observation may seem counterintuitive, but it can be explained considering Figure 4, which analyses the average saturation of a truck in relation to the number of served stores per route for the training company. Indeed, when the number of served stores per route increases, the average truck saturation and the average stores' distance from the DC increase as well, highlighting the greater effort carried out for the optimization of distribution operations.

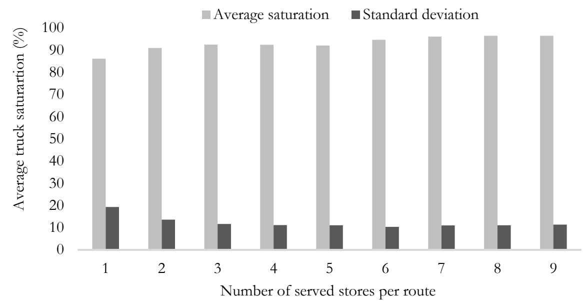

Figure 4: average truck saturation, per number of served stores

- Figure 5 shows the relationship between the daily turnover expressed in €/000 and the daily number of distribution routes, which appears to be a linear function. In addition, re-arranging the relationship it is possible to obtain the transfer function, which will be used to estimate the average number of distribution routes in the specific time horizon for the company i (AR_i). Note that the transfer function considers only the company turnover in the whole time horizon ($Turnover_i$). Hence, the expression is given as follows

$$AR_i = Turnover_i \cdot \frac{0.09807}{1000} = Turnover_i \cdot c_1 \quad (2)$$

where $c_1 = 0.00009807$.

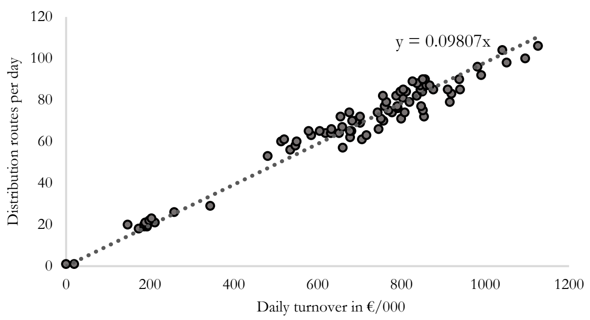

Figure 5: relationship between daily distribution routes and turnover

This is reasonable because the c_1 coefficient is tied to the average value of the good transported by one truck, which is a fairly constant value averaging 10k€.

3.4 Distribution costs estimation for the test company

This subsection shows *step 4* and *step 5* of the aforedescribed methodology, which respectively entail the calculation of the distribution network parameters for the test company and – in turn – the estimation of its distribution costs. Hence, the case study of the test company is here provided, in order to validate the relationships and transfer functions previously introduced.

Differently from the training company, the subject of the case study had only few available data, consisting of:

- the stores' addresses, that indicate an average distance from the DC of 108 km ($ADDC_{test} = 108\ km$);
- the company sales from 01/02/2019 to 14/05/2019, with an average monthly turnover of 15.8 M€ (that leads to an overall turnover in the whole time horizon of $Turnover_{test} = 55.3\ M€$);
- the actual distribution cost from 01/02/2019 to 14/05/2019, which is equal to 1.615 M€ ($TADC_{test} = 1.615\ M€$).

Hence, according to (1) and (2), from the given dataset the following estimations are given:

$$ASSR_{test} = 4.54\ stores/route \quad (3)$$

$$AR_{test} = 5'424\ \ distribution\ routes \quad (4)$$

It is now possible to compute the estimate for the total travelled km of the test company ($TTkm_{test}$), according to the following formula

$$TTkm_{test} = ADDC_{test} \cdot ASSR_{test} \cdot Slope_{ASSR_{test}} \cdot AR_{test} \quad (5)$$

where $Slope_{ASSR_{test}}$ represents the regression coefficient corresponding to the average number of served stores per route ($ASSR_{test}$). Moreover, it is interesting to observe that the product $ADDC_{test} \cdot ASSR_{test} \cdot Slope_{ASSR_{test}}$ represents the average travelled km in a route, which is multiplied for the average number of routes in the whole time horizon (AR_{test}) for obtaining the overall travelled km estimation.

However, there is no corresponding regression to the estimated $ASSR_{test}$. Thus, the slope can be computed through an interpolation of the regression values close to $ASSR_{test} = 4.54$, namely $ASSR_{training,4} = 4$ (whose corresponding slope is $Slope_{ASSR_{training,4}} = 0.571$) and $ASSR_{training,5} = 5$ (whose corresponding slope is $Slope_{ASSR_{training,5}} = 0.459$). Considering these data, the linear interpolation gives:

$$Slope_{ASSR_{test}} = 0.5103 \quad (6)$$

Therefore, it is now possible to compute the total estimated travelled km of the test company in the whole time horizon. According to (5), the estimation leads to:

$$TTkm_{test} = 1'357'728\ km \quad (7)$$

Moreover, assuming the test company management specified transportation fare of $f_{test} = 1.2\ €/km$, its total estimated distribution cost ($TEDC_{test}$) results as follows

$$TEDC_{test} = f_{test} \cdot TTkm_{test} = 1.630\ M€ \quad (8)$$

which leads to an overall estimation error of 0.93%, since the total actual distribution cost of the test company during the considered time horizon is $TADC_{test} = 1.615\ M€$.

4. Conclusions and further developments

This research aimed at identifying a simple and effective method for estimating the distribution cost of a LSRT company, leveraging only on commonly available data to managers (i.e. stores' addresses, turnover). The proposed methodology has proved to be consistent on very dissimilar cases, with a minor estimation error (0.93%) on a case study of a large LSRT Italian company. Hence, this paper provides a reliable tool for supporting strategic decision-making processes in LSRT companies and performs an application to a real industrial case.

The proposed method exploits a set of functions which have been calibrated onto the case of a training company, and then validated onto the case study of a test company. Both companies are major firms and leaders in the Italian market, but operate in different contexts and with distinct distribution configurations. Through the usage of simple linear regression analysis, the stores' location has been correlated with the total travelled distance in a distribution route, finding several linear expressions related to the specific number of served stores per route. In addition, two transfer functions have been defined in order to take into account the different distribution configurations. Therefore, leveraging only on test company stores' addresses and turnover, it has been possible to successfully estimate its distribution cost in the considered time horizon. Overall, our estimated results demonstrate a great consistency with the company actual registered results, showing the effectiveness of the proposed methodology.

This conclusion has several implications for researchers and industrial managers. Indeed, the application of the proposed methodology to the case study of a large LSRT Italian company showed that, even when there is small availability of data, these few data can be productively used to perform some estimations. Specifically, when the transportation fare is variable and directly related to the total travelled distance, the stores' addresses and an estimation of their overall turnover are sufficient to estimate the total distribution cost of a LSRT company, with an estimation error lower than 1%. Moreover, our contribution could be adopted by LSRT managers as a practical support to decision-making activities: particularly, the estimation of the company distribution cost resulting from a specific distribution configuration could be used for the evaluation of DCs opening/closure, considering the stores which will be served by the new/remaining DCs and their corresponding turnover. Hence, the aforedescribed methodology can support the development of business cases specifically tailored to the needs of LSRT companies.

Further applications to LSRT companies could help refining the methodology: for instance, truck saturation data can be compared to evaluate more in depth the different distribution configurations; beyond that, an extension of the proposed methodology either to the problem of product allocation to DCs, or to decisions related to product introduction/withdrawal may be considered. Obviously, these eventual extensions entail a more integrated approach to estimating the distribution cost, which steps into the distribution network design domain and requires additional data to be performed; in this sense, the authors suggest that caution should be paid to real data availability in any future research work focused on LSRT industry complexity.

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