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A Framework for Mitigating Excessive Transportation in the Context of Manufacturing Localization

E. Eryarsoy, H. Nalcioglu, H.S. Kilic, A.S. Yalcin, S. Zaim, and D. Delen

Abstract— **While the zeitgeist of today prescribes localization as a key to eliminate the excessive transportation for manufacturing firms, firm-level practical and workable guidelines that go beyond maxims are scant. Laden with analytical methods, this paper offers a phronetic, customizable framework based on Lean Six Sigma (LSS). The framework mimics Define-Measure-Analyze-Improve-Control (DMAIC) process. The early phases of the framework, ex-ante, prescribe the use of a variety tools and techniques from Lean Six sigma (LSS) and employ fuzzy analytic hierarchy process (FAHP) to extract the vital few root-causes that may impede localization. The latter phases suggest the use of design of experiments (DOE) to evaluate the root-causes, ex-post. The paper outlines a clear and established procedure and demonstrates each analytical phase using evidence from a two-year real-world application in steel industry.**

Index Terms—**AHP, fuzzy logic, inshoring, localization, offshoring, reshoring, transportation**

I. INTRODUCTION

PIETRA Rivoli [1] in her book "The Travels of a T-Shirt in the Global Economy" tells the compelling story of a t-shirt from the cotton fields in Texas to a factory in China, the largest buyer of US cotton, back to the US through Panama Canal to Miami, then through Salvation Army bins to Tanzania as hand-me-downs. The book elucidates the economic and social implications of extensive transportation in global supply chains and highlights some of the overarching issues with this transportation in the short run. Additionally, it implies that the majority of transportation occurs as a result of this excessive mobility. Offshoring is the practice of transferring select business processes to other countries. More recently. however, many firms have reversed a significant portion of their offshoring decisions [2] due to a variety of reasons such as interruption risks [3]. In this study, we use the term localization as an alternative to offshoring to refer to the process of elimination of excessive transportation of goods and returning the production to the manufacturer's original country.

The two competing tendencies (i.e., localization vs. offshoring) illustrated in the examples above have created new challenges and opportunities for international and local decision-makers alike [4]. During the years, the very same factors that once steered offshoring, made firms turn their faces towards localization. This is why localization, at its core, could be viewed as the antipodal to offshoring. However, there are additional driving factors for the reversal revoking offshoring decisions, such as sustainability especially during disruptions. The extant literature on disruptions and firm performance is clear: once a disruption is announced, the average return instantly drops [5]. The tsunami that struck the nuclear facility in 2011 was the bug in ear for GM [6]. More recently, COVID-19 pandemic has also caused a great deal of disruption, volatility and damage to firm performance worldwide. No previous disruption, including wars, has led to such drastic market swings in the 120 years of US stock market history [7].

These events have promoted topics such as sustainability and resilience in the body of localization-related literature [8]. The Reshoring Initiative reports over 1 million jobs created as a result of localization within the US [9]. Similarly, BDO Manufacturing CFO Outlook Survey [10] revealed that 22% of the companies explicitly stated their intention to relocate to the US, while another 25% were planning to relocate to another less volatile, or nearby country [9]. A quarter of the respondents also indicated that they plan to conduct a risk assessment for their supply chains. The extant literature stresses the benefits of pursuing sustainability via localization from a range of different viewpoints unequivocally. Srai and Ane [11] list over forty different drivers of relocation decisions. They include quicker product development and replenishment, better location branding and communication, reduced costs of transportation and carbon footprint among the key drivers.

Despite the abundance of research on the driving forces,

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advantages, and drawbacks of offshoring and the overwhelming support in favor of localization, it is astounding that, to the best of our knowledge, no "individual" or "firm-level" practical guidelines exist in the literature. No previous research has provided a practical advice on how to transition from offshoring to localization. The objective of this study is to offer a practical framework towards localization at firm level. In this study, unlike Gray *et al.* [12], we limit ourselves to manufacturing sector, and do not consider the “sourcing” aspect of localization/offshoring in toto. To this end, we follow a phronetic approach to propose a framework that integrates a variety of tools including LSS methodology, FAHP and regression analysis. We illustrate our proposed framework on a real case in an international steel company.

The rest of the paper is organized as follows. We present an up-to-date literature review in the next section. The details pertaining to the methods employed in our framework as well as corresponding results are provided in Section III. We discuss the proposed framework’s technical details and its managerial implications in Section IV. Final section draws together the conclusion and future directions.

II. Literature Review

Most strategic facets of procurement that concerns the elimination of excessive transportation within manufacturing, offshoring and localization have been well-researched. Firms that are strategic in their procurement nurture long term and cooperative relationships which help achieve greater market responsiveness [13], or reduce transaction costs [14]. The extant literature also suggests strengthening close working relationships with a limited number of local suppliers [15]. However, the literature on instrumentalizing localization as a part of strategic procurement is still evolving, nascent, and fragmented. Extant research presents a variety of alternatives and definitions for the localization term depending on its contextual meaning [12], [16] [17]. We, therefore set out to delineate certain terms that have been used in the literature that can refer to a form of mitigation or elimination of excessive transportation activities such as localization/offshoring including insourcing/outsourcing, reshoring, and nearshoring. Table I outlines the use of these words in the literature.

TABLE I
Literature on Localization

Buy	Domestic	*Reshoring* [12], *Local outsourcing* [18], *Inshoring* [19], *Domestic sourcing* [20], *Near-reshoring* [21], *Localization* [22]
	Hybrid	*Nearshoring* [23] *Regional outsourcing* [18]
	Offshore	*Overseas outsourcing* [18]
Buy&Make	Domestic	*Plural sourcing* [24] *Concurrent sourcing* [25] *Hybrid insourcing* [20]
	Offshore	*Concurrent sourcing* [26]
Make	Domestic	*Reshoring* [27], *Domestic insourcing* [28], *Insourcing* [18], *Back-reshoring* [29], *Inshoring* [19], *Onshoring* [30], *Backshoring* [31], *Localization* [32] *Near-reshoring* [21]
	Hybrid	*Nearshoring* [33]
	Offshore	*International insourcing* [28] *Far-shoring* [28] *Further offshoring* [34]

Two terms, offshoring and outsourcing are used to refer to moving some portion of tasks to another firm or another subsidiary of the same firm either located in another country, or in another organization within the same geographical location in general. For instance, offshore-insourcing refers to establishing one’s subsidiary firm in a foreign country [35]. Reshoring or insourcing, on the other hand, is the process of returning the production of goods to the manufacturer’s original country. However, to a greater extent, these terms have been used equivocally to refer to the process of returning the production to the manufacturer’s original country. For example, following eclectic theory [36], Wu and Jia [37] use localization term in the context of western multinational enterprises as “producing and distributing a product within an emerging economy”. Whereas Meijboom and Voordijk [38] and also more recently Nandi *et al.* [8], use localization term to refer to “the placement of the physical facilities of the company and the geographic placement where these activities take place and where facilities are established”. Localization, according to Nandi *et al.* [8], may occur via (domestic) insourcing or reshoring. Although insourcing is the process of reintegrating previously offshored activity, reshoring refers to the process of reallocating order volumes to suppliers that are geographically nearby [17]. In our study, we adhere to the definition followed by Nandi *et al.* [8].

As offshoring related literature is important in studying localization, reasons for revoking offshoring decisions and reinstating localization are inextricably linked. A vast majority of earlier studies highlight the benefits of offshoring (e.g. [27], [39]), while the extant literature on localization is nascent [8], [40]. Our study is motivated by the factors and motivations regarding localization decisions. As noted, ensuing offshoring, localization-related literature discusses risks and benefits of the reversal of offshoring. Kremic *et al.* [41] organize major motivations driving the offshoring decisions under three major categories: (i) cost, (ii) strategy and (iii) politics. They provide a very good overview of the earlier research regarding benefits sought and potential risks due to offshoring including these aforementioned motivation factors. First, in terms of cost, their study highlights cost savings due to lower supply costs attained via specialization, improved cost and cost management and the conversion of fixed expenses into variable ones. Second, in terms of strategy, the study mentions the benefits of being able to focus on core competencies thanks to outsourcing non-strategic parts and the greater flexibility outsourcing presents to cope with demand oscillations. Finally, in terms of politics, the

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authors mention public opinion or national/international trends among the risk and benefit drivers regarding offshoring decisions.

Kinkel and Maloca [42] claim that favoring localization is simply due to failing to realize benefits from offshoring. Hence much of the emphasis, remained on cost reduction until 2005 [43],[44]. However, the more recently accumulating localization-related body of literature has identified and stresseed additional factors such as vulnerability, resilience, and agility [8], supply chain sustainability and logistics stability [27], reducing supply lead time variability [45], better assessing sustainability [46], better coordination and sharing of information [47], environmental and sustainability issues [48], sustainability and environmental concerns [49] and increasing resilience [8].

The literature presents ample evidence that promotes building localization for a variety of reasons. Our study treats localization as an objective and focuses on increasing localization at item-level. Our proposed framework is motivation/focus agnostic. To the best of our knowledge, there has been no attempt to design a framework for localization at the item level. Noting this lacuna, this study, contributes to the extant literature by providing a structured practical framework towards localization. In addition, we demonstrate the framework on a global manufacturing firm, and present our results.

III. The Proposed Framework

Our study aims at building a localization framework that mitigates or eliminates unnecessary transport by improving procurement processes within manufacturing organizations. To this end, there are multiple existing process improvement techniques that could be used as a springboard towards establishing a custom-built framework [50], [51]. Choosing one of these well-used techniques enables decision makers not only to be able to make use of the vast selection of available tools and diagrams but also benefit from the well-developed body of literature that highlights risks, challenges, and critical success factors pertaining to its use [52]. Among the most well-known techniques are, six sigma, lean management, and total quality management (TQM). Six sigma and lean have a complementary relationship and are often time jointly referred to as LSS (lean six sigma) [53]. There are ample studies highlighting their similarities and contrasting their techniques, such as Andersson *et al.* [54]. Our framework mimics DMAIC framework of LSS and extends it with FAHP and DOE with linear models.

The first stage of DMAIC, “Define” entails the definition of localization problem and an associated metric, objectives, an understanding of the localization process problem, goal statements and process maps. This is followed by "Measure" stage, which focuses on the development and measurement of specified metric (Local ratio, in our case), and graphical visualizations of the selected metric. "Analyze" step involves identifying the root causes and/or source of variations for the selected metric. In the “Improve” stage, new processes are built to improve performance based on the selected metric, and ideas and solutions are formed to eliminate the root causes. In the last stage, "Control," tolerance variables are formed to oversee the process. Fig.1 provides a visual representation of the DMAIC process, with proposed tools and techniques for each of its stages as our framework prescribes.

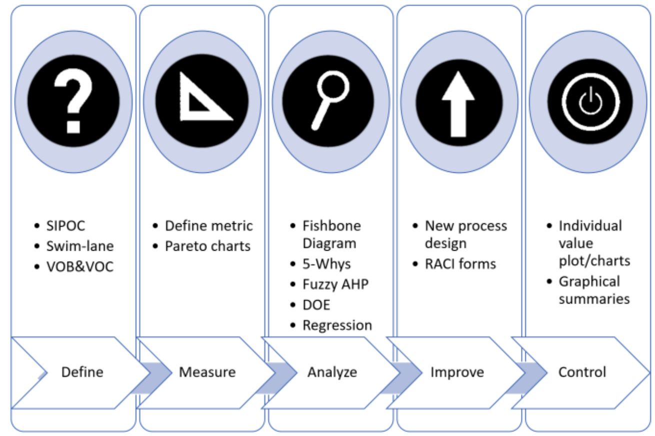

Fig. 1. Visual representation of the proposed DMAIC-based framework

We apply the proposed framework (Fig.1) in a multinational steel company (the firm, henceforth) that operates in various countries of the world. However, the project is performed in their subsidiary in Turkey. At the time of the execution, the firm was already familiar with LSS which was instrumental in the application’s success. The framework for the localization of the firm’s material supply, including alternative pathways was brought to the table in 2015, and the application started towards the end of 2016. In the following, we elaborate on each of the stages outlined.

A. Define

The main objective in applying the localization framework is to eliminate transportation, increase the localization and clarify benefits to be monitored and achieved through localization. At the end of this step (i) the problem is well-defined, suppliers & customers of the process are emphasized (ii) material sourcing processes are defined, and (iii) customer and business ownership wants and needs are highlighted.

Deciding on whether to pursue a localization project and determine its objectives is a strategic decision to be made by top management. Once the management decides on pursuing localization, a metric to measure primary objective, localization ratio (LC), in our case, should be operationalized as the primary metric. The benefits corresponding to all objectives are monitored throughout the application, however, no specific target figure is needed to be set for our framework to be applied. In our application case, the management of the firm was interested in increasing localization ratio increasing to eliminate unnecessary transport, reduce the lead time and cut down cost. The management also decided to monitor three added benefits (secondary objectives) throughout the application as lead time reduction, cost reduction, and lowering the localization ratio variability.

To understand the interplay between suppliers, input, processes, output and customers, the LSS offers a good

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selection of tools at this phase. Among them, we believe three contribute to our framework the most: (i) SIPOC diagram, (ii) Swim-lane detailed process map, and (iii) Voice of customer and voice of business (VOC&VOB). SIPOC diagram is used to document the supply process end-to-end. In Fig.2 we share the SIPOC diagram of the firm's supply process. We also provide swim-lane map (ApFig.1) and VOC&VOB (ApFig.2) in the Appendix. for interested readers. The usage of these tools is optional, and substitutable.

In our application, the departments of production, maintenance and quality determine the needs and requests from the procurement department. Once technical departments prepare PR (Purchase Requisition) the purchasing process officially starts as regulation in the company. Outputs of the process are PO (Purchase Orders), qualified material, on-time delivery, and optimum stock level. Process customers are the suppliers except for the finance department.

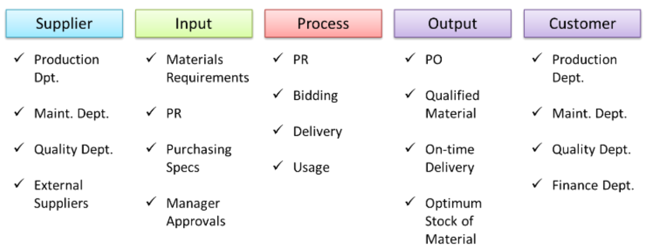

Fig. 2. SIPOC diagram for the firm.

In our case, following SIPOC diagram (Fig. 2) the firm detailed each process step and its owner. Each localization process begins with determining requirements. Technical departments prepare required documentation for the requisition of the material and create purchase request. Procurement then commences the sourcing procedure, which comprises bidding, selecting an appropriate supplier, and ordering. Accordingly, the warehouse receives the ordered materials. The procedure concludes with the material's use in the manufacturing.

B. Measure

This phase further develops and measures the primary (LR) and secondary metrics (the monitored benefits) of the study and related data regarding localization. To this end, the framework proposes a further specification of the metrics, and depicts their progress (and/or variability) over time using a series of charts for each of the objectives. While LR is the primary metric, it could be measured in terms of the LR of SKUs, monetary value, or volume. Deciding on how to measure is usually driven by the secondary objectives of the study. For instance, cost minimization leads to computing LR in terms of monetary value, or LR in time units could be used to monitor and achieve lead time reduction as the secondary objective.

In our application, we defined LR as the proportion of the number of locally purchased items, and measured the current LR as 30.5%, a lower figure compared to other subsidiaries of the company (in other countries, for example in Thailand subsidiary of the firm the local ratio was measured as 50%). We also decided to monitor lead times, and measured the average lead time (per item, unweighted) as 35 days at the beginning of the project. Other secondary objectives to be monitored, lead time reduction, cost reduction, and lowering the localization ratio variability were also visualized. We depict LR progress in Fig.3. For each year, pareto charts could be operationalized to reidentify and track key materials towards localization (see ApFig.3).

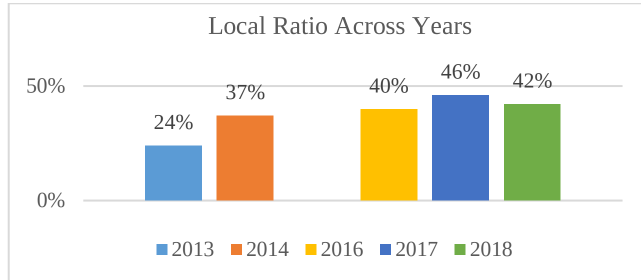

Fig. 3. Local ratio in years before (2013-2014) and after (2016-2018) the project application during 2016.

C. Analyze

This phase carries two main objectives (i) the extraction of possible root causes of the problem, and (ii) the filtering of these causes to be used in design of experiments (DOE) for analytical tractability (if needed). Localization applications span multiple areas of procurement and involve multiple decision-makers, or experts jointly working on the problem on hand. The process of assembling root causes into a final set involves using domain expertise. It is expected that a significant percentage of an issue will be resolved if its root causes are addressed. Therefore, the vital few root causes are extracted using Fishbone Diagram (Fig.4).

The vital few list necessitates the use of Analytic Hierarchy Process (AHP) possible, which has been proven effective in analyzing complex decisions and expert opinion fusing [55]. AHP relies on pair-wise comparisons, through which stakeholders assess the relevance of two criteria (or root causes) at a time. It enables the removal of less significant root causes via comparative assessment. We discuss each step of "Analyze" stage below.

Setup Step (Fishbone diagram): In order to perform the root cause analysis to identify and cluster the direct effects on LR our framework suggests using Fishbone Diagram. This helps identify and organize all root causes under predefined categories (see Fig.4). In root-cause analysis, it is considered that resolving the problem's fundamental cause resolves a substantial portion of the problem. While not required, within the framework, the identified root causes can be confirmed by consensus using methods such as 5-Whys.

In our application a fishbone diagram was produced that identified and categorized 15 distinct root causes (Fig.4 and Table II). The analysis was performed by two procurement specialists and two technical department specialists and all root causes in the diagram are confirmed by consensus using 5-Whys method.

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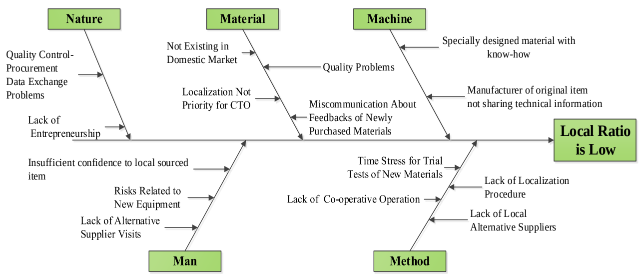

Fig. 4. Fishbone Diagram of Low Local Ratio

TABLE II

REASONS AND REASON CATEGORIES FOR LOW LOCAL RATIO

No	Cause	Cause Category
R1	Quality Control-Procurement data exchange problems	Nature
R2	Lack of entrepreneurship	
R3	Not existing in domestic market	Material
R4	Localization not priority for CTO	
R5	Quality problems	
R6	Miscommunication about feedbacks of newly purchased materials	
R7	Specially designed material with know-how	Machine
R8	Manufacturer of original item not sharing technical information	
R9	Insufficient confidence to local sourced item	Man
R10	Risks related to new equipment	
R11	Lack of alternative supplier visits	
R12	Time stress for trial tests of new materials	Method
R13	Lack of Co-operative Operation	
R14	Lack of localization procedure	
R15	Lack of local alternative suppliers	

AHP relies on pair-wise comparisons (of root-causes). AHP, due to its independency assumption, cannot factor in interactions among the items. Therefore, the experts are cautioned about extracting independent root-causes during the extraction step. Corresponding discussions among the experts regarding the pair-wise comparisons of root-causes typically involve uncertainties when decision-makers attempt to use the typical 1-9 scale of AHP. To represent these uncertainties, decision makers desire more malleable scales via the use of fuzzy membership functions and linguistic variables such as excellent or poor rather than crisp values [56]. The technique has been successfully applied to manufacturing domain [57]. The research on fuzzy memberships in AHP (FAHP) is expanding, and several FAHP modifications have been published [58]. In this study, FAHP is utilized to determine the priorities of low LR causes. The FAHP application procedure proposed by Buckley [59] was followed as detailed in the remaining steps.

Step 1 (FAHP initialization): After the experts conclude that the interactions between the causes do not pose an issue the identified drivers (root causes) of the chosen metric are fed into FAHP to extract the vital few and get rid of the trivial many. The comparison of two factors (criteria or alternatives) is performed by the decision makers at each time via the linguistic scale consisting of the fuzzy preference scale as shown in Table III [60].

TABLE III

TRIANGULAR FUZZY PREFERENCE SCALE

Scale of Saaty	Explanation	Triangular fuzzy scale
1	Equal importance	(1, 1, 1)
3	Moderate importance of one over another	(2, 3, 4)
5	Essential or strong importance	(4, 5, 6)
7	Demonstrated importance	(6, 7, 8)
9	Extreme importance	(9, 9, 9)
2		(1, 2, 3)
4	Intermediate values between	(3, 4, 5)
6	two adjacent judgments	(5, 6, 7)
8		(7, 8, 9)

During the step, the pair-wise comparison matrices are formed following Eq.1. where $\tilde{d}_{ij}^{k}$ indicates the kth decision maker's preference set of one factor over another.

$$\tilde{A}^{k}=\begin{bmatrix}\tilde{d}_{11}^{k} & \tilde{d}_{12}^{k} & \dots & \tilde{d}_{1n}^{k}\\ \tilde{d}_{21}^{k} & \dots & \dots & \tilde{d}_{2n}^{k}\\ \dots & \dots & \dots & \dots\\ \tilde{d}_{n1}^{k} & \tilde{d}_{n2}^{k} & \dots & \tilde{d}_{nn}^{k}\end{bmatrix} \quad (1)$$

In our application, the pairwise comparison matrices for main and sub-reasons (Fig. 5) were determined via the consensus of the four specialists. Then the first matrix that includes the comparison of the main reasons (Table IV) and the matrices corresponding to the pair-wise comparison of the sub-reasons based on the triangular fuzzy numbers (Table V) were computed.

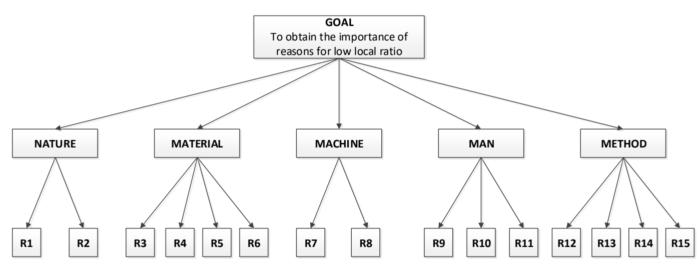

Fig. 5. The hierarchical structure for determining the importance of reasons

TABLE IV

PAIRWISE COMPARISON OF THE MAIN REASONS BASED ON THE TRIANGULAR FUZZY NUMBERS

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	Nature	Material	Machine	Man	Method
Nature	(1,1,1)	(1/5, ¼, 1/3)	(1/6, 1/5, ¼)	(1/3, ½, 1)	(1/8, 1/7, 1/6)
Material	(3,4,5)	(1,1,1)	(1,1,1)	(1,2,3)	(1/3, ½, 1)
Machine	(4,5,6)	(1,1,1)	(1,1,1)	(1,2,3)	(1/3, ½, 1)
Man	(1,2,3)	(1/3, ½, 1)	(1/3, ½, 1)	(1,1,1)	(1/4, 1/3, ½)
Method	(6,7,8)	(1,2,3)	(1,2,3)	(2,3,4)	(1,1,1)

TABLE V
PAIRWISE COMPARISON OF THE SUB-REASONS UNDER MAIN REASONS BASED ON THE TRIANGULAR FUZZY NUMBERS

Nature	R1	R2		
R1	(1,1,1)	(1/3, ½, 1)		
R2	(1,2,3)	(1,1,1)		
Material	**R3**	**R4**	**R5**	**R6**
R3	(1,1,1)	(1/3, ½, 1)	(1,1,1)	(1,2,3)
R4	(1,2,3)	(1,1,1)	(1,2,3)	(2,3,4)
R5	(1,1,1)	(1/3, ½, 1)	(1,1,1)	(1,1,1)
R6	(1/3, ½, 1)	(1/4, 1/3, ½)	(1,1,1)	(1,1,1)
Machine	**R7**	**R8**		
R7	(1,1,1)	(1/3, ½, 1)		
R8	(1,2,3)	(1,1,1)		
Man	**R9**	**R10**	**R11**	
R9	(1,1,1)	(1,2,3)	(2,3,4)	
R10	(1/3, ½, 1)	(1,1,1)	(1,2,3)	
R11	(1/4, 1/3, ½)	(1/3, ½, 1)	(1,1,1)	
Method	**R12**	**R13**	**R14**	**R15**
R12	(1,1,1)	(1,2,3)	(1/8, 1/7, 1/6)	(1,2,3)
R13	(1/3, ½, 1)	(1,1,1)	(1/9, 1/9, 1/9)	(1,1,1)
R14	(6,7,8)	(9,9,9)	(1,1,1)	(9,9,9)
R15	(1/3, ½, 1)	(1,1,1)	(1/9, 1/9, 1/9)	(1,1,1)

Step 2 (Inconsistency check): The inconsistency of each comparison matrix is calculated. In FAHP, firstly, the related matrix is defuzzified as in Eq. 2 [61]. Then, the Saaty's consistency procedure is applied. Inconsistency ratios less than 0.10 are considered acceptable. Else, the respective comparison matrix is not accepted and reconsidered. In our case, the computed inconsistency values were less than 0.1.

$$D(\tilde{d}_{ij}) = \frac{l+4m+u}{6} \quad (2)$$

Step 3 (Averaging): If the number of decision makers is more than one, then, the arithmetic average ($\tilde{d}_{ij}$) of all (K) decision makers' judgment values are computed as in Eq. 3. This step is skipped in our application since compromise judgments were used in the pairwise comparison matrices.

$$\tilde{d}_{ij} = \frac{\sum_{k=1}^{K} \tilde{d}_{ij}^{k}}{K} \quad (3)$$

Step 4 (Compute factor weights): Each factor's fuzzy weights are obtained via the geometric mean method proposed by Buckley [59]. Firstly, the geometric means of fuzzy comparison value of factor *i* to each factor are computed as in Eq. 4.

$$\tilde{r}_i = \left(\prod_{j=1}^{n} \tilde{d}_{ij}\right)^{1/n}, \quad i=1, 2,..., n \quad (4)$$

Then, the fuzzy weight of the *i*th factor represented by a triangular fuzzy number is obtained as in Eq. 5.

$$\widetilde{w}_i = \tilde{r}_i \otimes (\tilde{r}_1 \oplus \tilde{r}_2 \oplus \cdots \oplus \tilde{r}_n)^{-1} = (lw_i, mw_i, uw_i) \quad (5)$$

In our application, the fuzzy weight ($\widetilde{w}_i$) of each main reason and sub-reason was obtained from the comparison matrices as shown in Table VI.

TABLE VI
FUZZY WEIGHTS OF THE REASONS

	Reason	Fuzzy weight
Main Reasons	Nature	(0.033, 0.053, 0.095)
	Material	(0.123, 0.215, 0.385)
	Machine	(0.131, 0.224, 0.400)
	Man	(0.060, 0.114, 0.243)
	Method	(0.203, 0.395, 0.696)
Sub-Reasons	R1	(0.211, 0.333, 0.634)
	R2	(0.366, 0.667, 1.098)
	R3	(0.136, 0.230, 0.405)
	R4	(0.212, 0.429, 0.755)
	R5	(0.136, 0.194, 0.308)
	R6	(0.096, 0.147, 0.259)
	R7	(0.211, 0.333, 0.634)
	R8	(0.366, 0.667, 1.098)
	R9	(0.278, 0.540, 0.958)
	R10	(0.153, 0.297, 0.603)
	R11	(0.097, 0.163, 0.332)
	R12	(0.081, 0.129, 0.179)
	R13	(0.060, 0.072, 0.094)
	R14	(0.643, 0.726, 0.818)
	R15	(0.060, 0.072, 0.094)

Step 5 (COA): Centre of Area (COA) method is used as the defuzzification method [62]. The nonfuzzy value M_i of the fuzzy number $\widetilde{w}_i$ is determined using Eq. 6 where M_i is a nonfuzzy number. The normalized weights N_i are obtained by normalization.

$$M_i = \frac{lw_i+mw_i+uw_i}{3} \quad (6)$$

Table VII provides the M_i and N_i values corresponding to the main reasons in our application.

TABLE VII
M_i AND N_i VALUES FOR THE MAIN- AND SUB-REASONS

	Reason	M_i	N_i
Main Reasons	Nature	0.060	0.054
	Material	0.241	0.215
	Machine	0.252	0.224
	Man	0.139	0.124
	Method	0.431	0.384
Sub-Reasons	R1	0.39	0.36
	R2	0.71	0.64
	R3	0.26	0.23
	R4	0.47	0.42
	R5	0.21	0.19
	R6	0.17	0.15
	R7	0.39	0.36
	R8	0.71	0.64
	R9	0.59	0.52
	R10	0.35	0.31
	R11	0.2	0.17
	R12	0.13	0.13
	R13	0.08	0.07
	R14	0.73	0.72
	R15	0.08	0.07

Step 6 (Factor global weights): After determining each M_i, all factor's global weights (W_i) are obtained by multiplying the local normalized weights of the criteria by the related dimension's normalized weights. Table VIII shows the local and global weights of the sub-reasons in decreasing order for our application.

TABLE VIII
LOCAL AND GLOBAL WEIGHTS OF THE SUB-REASONS

Reasons	**Local weight**	**Global weight**
R14	0.722	0.2771
R8	0.6439	0.1442
R4	0.4221	0.0906
R7	0.3561	0.0798
R9	0.519	0.0642
R3	0.2333	0.0501
R12	0.1288	0.0494
R5	0.1928	0.0414
R10	0.3079	0.0381
R2	0.6439	0.0346
R6	0.1519	0.0326
R13	0.0746	0.0286
R15	0.0746	0.0286
R11	0.173	0.0214
R1	0.3561	0.0191

After ranking the sub-reasons of low LR, the group decides to choose a subset of the sub-reasons based on their global weights. Here, the next question is deciding on the final size of root causes to be used in DOE. Each of these experiments will involve a modification to the purchasing process, therefore is costly and requires a lot of effort. Therefore, the final root cause list size will be application-specific. There are several ways of distilling expert opinions into a shorter root cause list, including voting, or more sophisticated methods like AHP. In our case, the decision-makers selected top five sub-reasons as vital few as shown in Fig. 6.

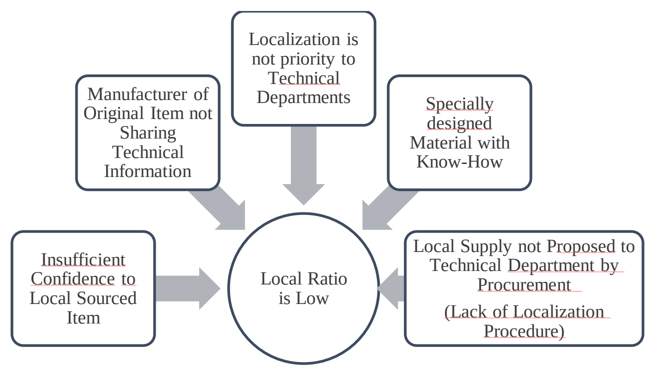

Fig.6. Vital Few of Low Local Ratio

Step 7 (DOE): To bridge the gap between expert-suggested causes and the actual ones to be identified in the application, our framework suggests the implementation of DOE. DOE is used to explain the response variable, the success in localization depending on varying contribution factors as the input variables. In our case, all input variables were dichotomous. One possible way to conduct DOE is by creating a fully crossed design of the variables.

In our case, following FAHP, the decision-makers decided to pursue a fully crossed design for all the items for localization. Therefore, our DOE involved a full factorial design with all items using weighted regression where the weights correspond to the item counts for each factor combination. This setting also enabled testing different interaction terms among our root causes in our analysis. This way, we were also able to address a possible shortcoming of AHP, the no-interaction assumption.

We made use of an LSS tool, fishbone diagram by two procurement specialists and two technical department specialists. The number of items to be localized was 583 and corresponded to 20 unique combinations (out of 2^5=32). Table IX outlines the cases, the number of items to be localized for each instance, and case success/failure status at the completion of the application. While there are ways to shorten the number of items to be localized to reduce the number of experiments, in our study decision-makers decided to follow a fully crossed design. After transforming our dataset, due to the imbalanced nature of the dataset, we used weighted logistic regression model to perform an ex-post evaluation of the root-causes. We used Generalized Linear Model (glm) library in R (3.6.2) for our analysis.

TABLE IX
THE BREAKDOWN OF CASES AND NUMBER OF ITEMS

Case	R4	R7	R8	R9	R14	# of succes	# of fail
1	1	0	1	1	0	3	7
2	1	1	1	0	0	12	5
3	0	0	0	0	0	327	0
4	1	1	0	1	0	5	7
5	0	1	1	1	0	1	2
6	0	0	1	0	0	6	0
7	1	0	0	0	0	19	1
8	0	1	0	0	0	4	0
9	1	1	0	0	0	4	0
10	1	0	0	1	0	4	44
11	0	1	1	0	0	18	5
12	1	1	0	1	1	3	0
13	1	0	0	0	1	16	0
14	1	0	1	0	0	4	0
15	0	0	1	1	0	2	0
16	1	1	1	1	0	19	36
17	0	0	0	1	0	1	0
18	1	0	0	1	1	1	21
19	0	1	1	0	1	3	1
20	1	0	1	0	1	1	1
					Grand Total	**583**	

In weighted logistic regression models, a negative sign for the coefficient means that the independent variable decreases the probability of the event occurring, whereas a positive sign indicates the independent variables increase the likelihood of the event. The maximum likelihood estimation method is used for the logistic regression analysis. Statistically, the value of −2 likelihood logarithm (-2LL) is employed to compare the goodness-of-fit of the intercept-only model with the full model including all independent variables. In this study, the chi-square difference test results show that the difference between the two values is computed as a score of 400 (618-218) with 6 degrees of freedom as significant. It indicates that the proposed model is valid and the independent variables improve the model fit. If odds ratio (OR) is significantly less than 1, then the existence of a certain problem is associated with a lower localization success level rather than a higher localization success level. Therefore, it suggests that the existing problem is essential and challenging to solve. OR significantly higher than 1 indicates that the presence of a particular problem is more likely to lead to less serious consequences and it shows that the existing problem can be solved easily by the company. When the OR is close to 1, the likelihood of each consequence level caused by this factor is almost the same.

The analysis showed that the model could accommodate additional interaction effects (R7:R8 and R8:R9). With the exception of "R14: Lack of Localization Procedure" root cause, all other root causes were found to be significant factors. The analysis also suggested interaction effects that were not identified during FAHP. While the standardized coefficients of regressions (Table X) and FAHP weights (Table VIII) are not correlated, with the exception of R14, all coefficients corresponding to FAHP factors were found to be significant. The interaction effects suggest that when the item is specially designed (R7) and its manufacturer is not sharing technical information (R8) then there is a slimmer chance of successful localization. The statistical significance of interaction terms also suggests that at step 1 of "Analyze" stage, the experts' judgment that interactions between causes do not constitute an issue is questionable.

TABLE X
REGRESSION RESULTS

Variable	Coeff	p	Odds	CI-Upper
Int	6.09	<.001	-	8.06
R4	-1.11	<.05	0.3	-5.12
R7	2.53	<.001	12.6	-1.51
R8	-3.77	<.01	0.0	-0.08
R9	-7.36	<.001	0.0	3.86
R14	-0.09	>.1	0.9	-1.45
R7:R8	-3.12	<.001	0.0	8.30
R8:R9	5.96	<.001	387.3	

Null deviance: 618, df=30; Resid deviance: 219, df=24; AIC=233.23,

While the results for the regression analysis are provided in Table X, they cannot be easily generalized to other localization applications. However, they show that considering DOE and FAHP results jointly bridges the gap between ex-ante (FAHP) and ex-post (DOE) evaluations.

D. Improve

The phase involves idea and solution generation against the root causes. The validated root causes are handled by generating new solutions which are instrumentalized via new regulations or forms. Our framework suggests new process design and Responsible-Approval-Control-Information (RACI) forms for the new processes.

In our application, these causes were eliminated, and new material procurement processes were formed. The results are given in Table XI. Fig.7. depicts a sample design for the

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substitute material purchasing produced in our application.

TABLE XI
VALIDATED ROOT CAUSES AND GENERATED IDEAS

No	Validated Root Cause	New Regulation or Form	Generated Idea(s)
R8	Manufacturer of Original Item not Sharing Technical Information	Substitute Material Purchasing Regulation and MRO Material Performance and Claim Report	Gathering all items' technical data in one common folder of the Steel Company.
R9	Insufficient Confidence to Local Sourced Item		Developing the quality assurance activities by new forms and using Substitute Material Purchasing Regulation
R4	Localization is not priority to Technical Departments	Revising Request Form	Involving technical departments to develop Local sources for every purchasing requisition
R14	Local Supply not Proposed to Technical Department by Procurement	Substitute Material Purchasing Regulation	Proposing Localization systematically to technical departments for every material
R7	Specially designed Material with Know-How	Revising Request Form	Finding original maker's local partners or distributors to receive faster support.

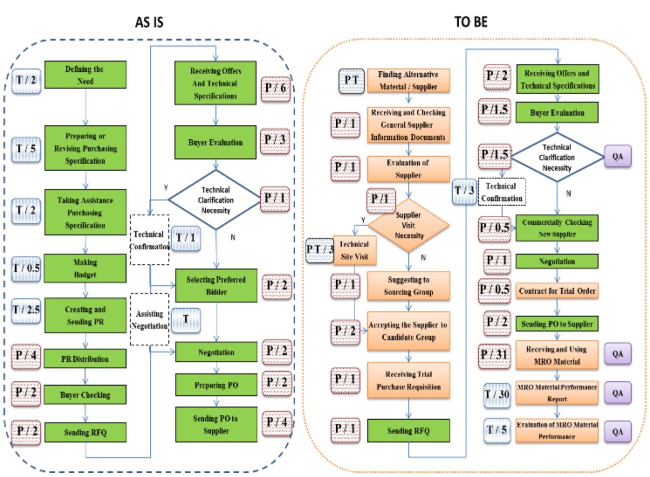


Fig.7. Current and New Process of the Substitute Material Purchasing

E. Control

Our last phase corresponds to "Control" phase of DMAIC. During this phase, the changes that have been agreed upon to develop new processes are implemented, recorded, and continuously monitored. A variety of tools such as control charts are designed and maintained, action plans to deal with deviations are formed, a timeframe for the solution to be implemented or not is determined, the new solution is labeled as "as is" or "business as usual". The control phase for localization checks the LR based on control parameters. An example control plan corresponding to our application project is given below. The control phase also shows the changes in LR, the before and after for both the primary and secondary project objectives. The control plan for our application case is given in Table XII.

TABLE XII
CONTROL PLAN

Control Parameter	Upper Specification/ Lower Specification	Controller	Reporting Responsible	Frequency of Control
Local Ratio (LR)	Min. 50%	Buyers	Buyers	Monthly
General Evaluation of Candidate Supplier	Min. 80%	Buyers	Buyers	Every Supplier Application
Potential Localization Items' Control	Min. 3 Material Group	Buyers	Buyers	Weekly
Ensuring Alternative Item's Quality and Performance	Conformity of the item	CTO Division	Quality Department	Each Trial Test
Total Saving Amount by Sep-16	Min. 340 Unit	Buyers	Buyers	Monthly

IV. DISCUSSION

A. Technical discussion

The framework described in this research offers significant technical simplifications for LSS practitioners and academics through a firm-level guideline for increasing localization. First, while the presented framework relies on DMAIC as a springboard, a number of its components are replaceable or configurable. For instance, root causes are identified throughout "Analyze" stage. Combining the fishbone diagram to extract key causes and using FAHP to fuse expert opinion, this phase identifies the essential few underlying causes and ranks them according to their estimated individual significance. Other methods such as maximum differential analysis (maxdiff) or conjoint analysis could replace FAHP. However, as conjoint analysis uses regression to estimate factor weights and is similar to AHP, it falls short in accommodating the independence of factors as it assumes preferential independence. However, there are adaptations to the conjoint analysis design that integrate factor interactions at the design stage, or during solution [63]. Other root-cause analysis methodologies, such as Kelly's repertory grid and failure mode and effect analysis, may be used alternately or in conjunction with the fishbone diagram.

Regardless of the method used to fuse expert opinion, however, the factor weights are prepared before any of the localization activities take place in the organization. They are established to serve as a strong starting point in the design of experiments. If the factor extraction process is expected to yield a long list of root causes, this will likely hinder the use of a fully crossed design during DOE stage. Therefore, three possible alternatives could be followed: (i) shortening the root cause list, (ii) following a fractional factorial design, (iii) a combination of both. This way, through DOE decision-makers could identify which root-causes are indeed easier to get rid of without exhausting each root-cause combination. In DOE, fractional designs, Hadamard matrices and orthogonal arrays or foldover design methods could be used. These methods can be used to include interaction of root causes (therefore increasing the number of experiments), or to shorten the list. Given our cause variables being dichotomous, typically a list of more than 8 items (2^8=256) will be infeasible. At this point, the decision makers could finalize localization project and focus on the elimination of the root causes or proceed to conduct series of experiments to better understand the variation in localization following root cause removal experiments. To this end, optimal designs that allow unbiased parameter estimation with minimum variance, or a non-optimal design requiring greater number of experimental runs could be constructed.

DOE results must also be monitored and checked against the multi-criteria decision making results under the analysis to address discrepancies between expert-opinion and realized results. In our case, the FAHP-postulated critical factors with greater weights (Table VIII) were also determined to be significant by ex-ante regression (Table X).

B. Managerial implications

Due to the earlier popularity of shifting business processes to other countries, many businesses already have offshoring embedded into their processes by design. Therefore, the reversal of offshoring is likely to require design alterations and modifications. This must be kept in mind throughout the Design stage of execution of the framework. Furthermore, identifying and evaluating local and regional alternatives at earliest stages of production design, planning equipment and production accordingly, will simplify the reversal of offshoring if conditions render this necessary. During the design, the transportation network should be taken into account in the same manner.

The steel firm where the application was submitted is based in Turkey, and its closeness to its main suppliers is certainly a location advantage. As this may not often be the case, it is imperative to evaluate exogenous drivers such as legal framework, transportation networks, and transportation infrastructure in prior, to be able to carry out a localization application further down the road when needed. Due to the fact that all of the equipment at the facility where the application was submitted was of foreign origin, several challenges were encountered as well.

V. Conclusion and Future Directions

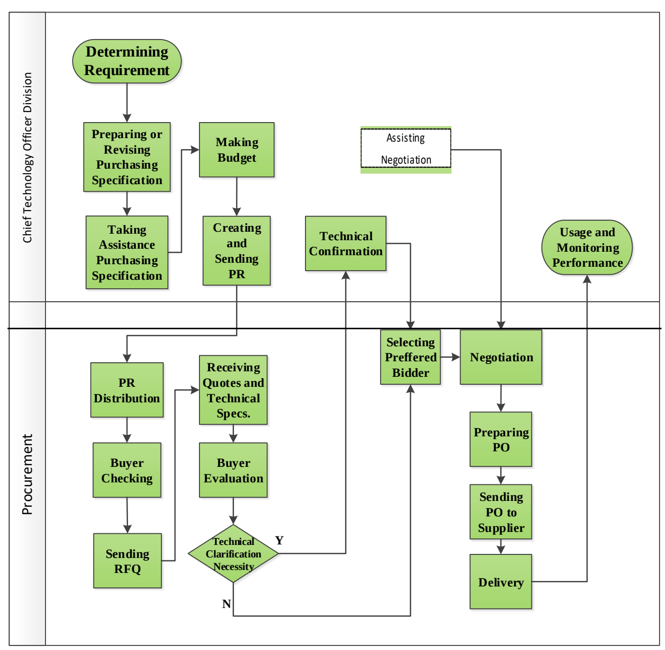
A significant portion of excessive transportation is attributable to excessive offshoring. Sustainable transport policies within manufacturing, therefore, are inevitably and inextricably linked to the mitigation of offshoring activities. Our literature review shows that such policies are recommended, however, there has been no attempt to design a step-by-step model that can help organizations mitigate excessive transportation and achieve localization.

While there are different techniques that could be used as a springboard towards the creation of a framework, this study used LSS as they are arguably the most frequently used. For instance, fuzzy conjoint analysis may be used as a substitute to FAHP, survey and Delphi approaches could replace fishbone diagrams for identifying the major root causes, I Chart of six-sigma can be used to monitor time series of local ratio. We mimicked and tailored DMAIC framework of LSS by annexing it with FAHP and DOE. FAHP makes fusing multiple subject matter experts' opinions to create an ex-ante evaluation of the list of root-causes, however, suffers from certain limitations such as no interaction effect among root-causes. While DOE is guided by FAHP, it also facilitates the ex-post evaluation of these root-causes. One of the key contributions of this study is to bridge the gap between ex-ante and ex-post evaluations of the root-causes.

This study also provides a clear, and proven pathway towards localization. The local ratio in the firm was increased from 30.5% to 42.5%, while the average lead time was reduced from 35 days to 19.5 within two years. The firm also achieved a significant cost reduction due to decreased lead times and cost savings (56.75%). While these results are firm-specific, they are also encouraging in that they indicate mitigating excessive transport can be pareto optimal both in terms of increased sustainability, and increased firm performance. Finally, the article encourages academics to apply the proposed framework to a variety of applications using other factors to eliminate wasteful transit in the context of production and LSS.

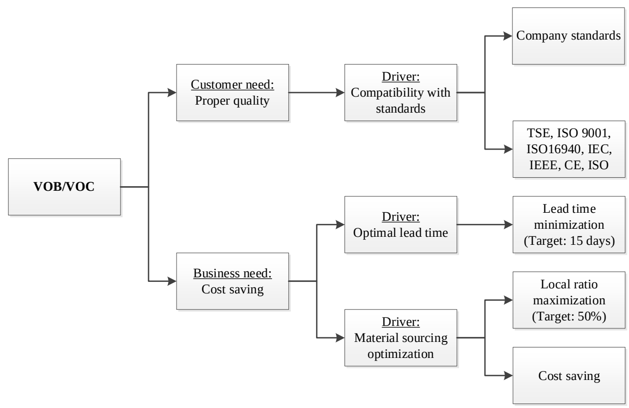
This study has several limitations that could be explored in future studies. For example, for a future study, an alternate framework to LSS might be adopted. Adopting different fuzzy preference scales could enrich the analysis. Alternatively, using fractional DOE designs can reduce the cost of experimentation significantly.

Appendix

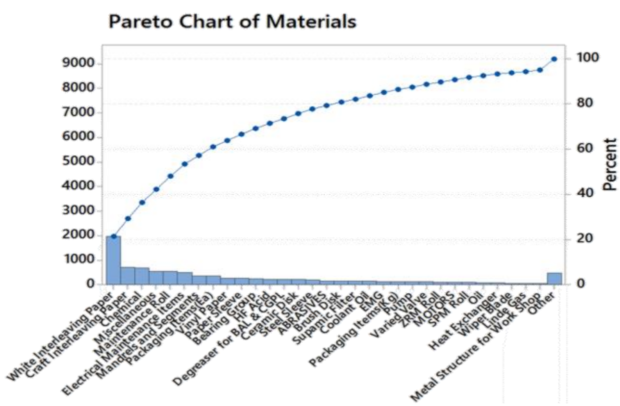


ApFig.1. Swim-lane Detailed Process Map. The map starts with Determining Material Requirements. Technical departments develop Purchase Requisition (PR) and compile the necessary paperwork for material requests. The Procurement then initiates sourcing process which includes

bidding, selecting appropriate supplier and material ordering. The procedure concludes with the usage of material in manufacturing. The map suggests that the critical steps are determining requirements, conducting a technical evaluation and usage.



ApFig. 2. VOB&VOC underlines that the company needs cost reduction, whereas the primary customer need is material quality.



ApFig.3. Pareto chart shows that 16 items occupy 80% of the contract amount, 9 of which are sourced from foreign suppliers, suggesting that these foreign-sourced items should be localized in order to raise the local ratio.

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