An operational framework for the definition of the supply chain strategies in ETO environments

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Abstract: This paper describes an operational methodology to support the project manager, in both proposal and management phases. The purpose of the proposed approach is to (i) estimate the criticality of the project both in terms of technical and management criticalities, (ii) identify the Business Partners (or suppliers) that it is most appropriate to involve in the project, (iii) estimate the expected direct and indirect costs of the project, and (iv) estimate the overall criticality of the project. In order to have an assessment of its validity and reliability, the proposed methodology is applied in a real project concerning the construction of an automated warehouse.

Keywords: project management; project criticality; risk management; suppliers management; automated warehouse.

1. Introduction and literature review

In Engineering To Order (ETO) organizations, which are well-known to be turbulent and complex work environments, the design, implementation and installation of complex products requires the main contractors to have recourse to external suppliers for the purchase of sub-projects and expertise. Because of this, in this type of organizations, companies are making every effort to improve the purchasing of existing projects (Zhang & Cao, 2018) starting from the proposal stage.
Project management is the organisational set-up of many sectors such as construction, shipbuilding, oil and gas, food plants, automated storage and retrieval system, automated intralogistics equipment. Within this contexts, the selection and the evaluation of the most suitable suppliers (San Cristóbal, 2012) are aspects of paramount importance to guarantee the success of the project (Araújo et al., 2017). Project procurement management deals with the identification and selection of the right suppliers, by assessing supply chain risks, or defining and subsequently managing the contracts awarded to suppliers (Project Management Institute, 2017). Working with suppliers includes various day-by-day activities to ensure that the planned work is carried out as agreed. In occasion of long terms partnerships, correctly identifying the business partner to operate with starting from the technical / economic offer is essential to improve the efficiency and effectiveness of the purchasing process (Grudinschi *et al.*, 2014).
It is important that these activities are carried out from the earliest stages of the project life cycle, and, if possible, brought forward from the proposal stage. The supplier selection requires considerable effort in any kind of organizations (Zolghadri *et al.*, 2011); and it is therefore important to identify a correct and methodical approach to follow.
In scientific literature, different approaches have been presented over the years for the selection of suppliers in ETO business contexts (Araújo *et al.*., 2017), few of which present a methodological framework that allows the choice of supplier to be integrated into the proposal process. In a relatively recent and interesting publication, Araújo *et al.* (2017), analyse the main methods adopted and criteria used for the selection and evaluation of suppliers in ETO environments, over a wide time horizon (from 1973 to 2015). The authors mainly analyse projects in the field of construction, but they well describe the criteria adopted in the selection of suppliers (such as quality, cost/price, staff features, financial, company management, experience and time), and report the main methods used for evaluation (e.g. multiple criteria based methods, fuzzy set methods, multi methodologies, structured framework, probability and statistical methods and so on).
It is interesting to note that, for many authors, such as Yeo and Ning (2002), a correct management of the project procurement phase could improve performance both in terms of productivity and profitability. Yeo and Ning, (2002) suggest the integration of supply chain management (SCM) and critical chain project management (CCPM) methods to manage risk and uncertainty in ETO projects. The presented approach is essentially a cultural and process review/improvement approach, however, it does not provide useful qualitative/quantitative tools for the project manager to assess the risk associated with different procurement scenarios (e.g., involvement of multiple suppliers in the project).
As a matter of fact, the project procurement management is fundamental to guarantee both the overall quality of the

project and the respect of the cost and the time schedule (Zhang, et al., 2013).

The most recent publications on project procurement management deal with identifying the right suppliers and establishing the best contracts with them to allocate risk and responsibility. This activity is usually carried out once the main contractor has acquired the project (Dragan et al., 2010). Integrating suppliers into the project organization during project execution is seen by many authors as an optimal solution for achieving high levels of efficiency and effectiveness in project management (Grudinschi et al., 2014).

This paper presents the results of a case study conducted with an EPC contractor in the field of intralogistics automation. The company involved wish to develop an operational framework that allows to integrate a procurement management approach into the project costing process starting from the proposal management phase. In this sense, during the proposal phase, the project manager has to compare different procurement and purchasing scenarios (e.g. several scenarios characterized by the involvement of different suppliers or business partners, both internal and external to the organization) from the point of view of the (i) overall project costs, and (ii) overall risk associated to each specific scenario. The proposed approach is generic enough to be applied in many other contexts, and could constitute a solid scientific contribution by partially filling the gap left by the absence of decisional models for the selection of suppliers beginning from the proposal phase.

The reminder of the paper is organised as follow. In the next section, a brief description of the proposed approach is reported. Then in section 3, a synthetically (for confidentiality reason, it is not possible to bring back all the useful information) description of the case study is reported. Section 4 contains the discussion of results and application insights. And, finally, the paper ends with some conclusive considerations about possible improvements of the proposed operational framework.

2.The approach

The proposed approach is based on the following steps.

1) Development of the qualified business partners / purchasing group matrix. This activity consists of the following steps:
   a) breaking down the *project's purchasing elements* into "homogeneous groups" called *purchasing groups* (PGs);
   b) identify the qualified business partners (BPs) from which to purchase each purchasing group.

   This preliminary step is useful to visualise and clearly identify the elements to be purchased (i.e., PG) and the possible suppliers considered (i.e., BP).
2) Estimation of the intrinsic (i.e., technical) complexity of the project by defining an *Intrinsic Complexity Index (ICI),* an index inspired by the well-known ICE index (Richard Schonberger, 1987). Different factors are defined for each PG and will be used to estimate its technical complexity, and the project team will have to carry out the evaluation of the factors (e.g., a qualitative evaluation) of each PG, thus estimating the technical complexity of each PG (ICI_{PG}).

   The combination of the technical complexity of each individual PG will make it possible to obtain a synthetic index of technical complexity of the project ($ICI_{project}$).
3) Estimate the extrinsic (i.e., environmental / managerial) complexity of the project by defining an *Extrinsic Complexity Index (ECI)*. The ECI is the respective of ICI, but it considers only external and environmental difficulties that does not concern the technical aspects in themselves. For each specific project, an overall estimate of the project complexity must be made with reference to the project environment (e.g. geographical area, stakeholder involved, etc.) and to the project scope. Technical aspects of the project are not considered in this evaluation. The distinction between internal and external factors that may affect the project has been inspired by Bertolini *et al.* (2021).
4) Identification of possible purchasing / procurement scenarios:
   a) once the business partners from whom the PGs can be purchased have been identified, and the economical offers for the relative parts have been collected, the possible purchasing solutions can be identified. In particular, following scenarios may be identified:
      i) a scenario in which there is only one business partner able to supply all PGs;
      ii) a scenario in which there are as many business partners as PGs (each business partner is responsible for a PG);
      iii) a potentially indefinite number of intermediate solutions between (i) and (ii).

      It is reasonable to believe that the cost of supply is lower when all PGs are purchased by a single business partner, although, this borderline situation involves an higher risk, since a hitch to the detriment of that supplier would slow down the whole project.
   b) for each a scenario, the following shall be determined:
      i) <u>Project Risk Index</u>, calculated considering (i) the intrinsic complexity index of the PGs, (ii) the qualification of the BPs and (iii) the extrinsic complexity index of the project;
      ii) <u>Total (supply) direct costs</u> (as the sum of the bids obtained from the BPs);
      iii) <u>Total Direct Cost of Field and Total Indirect Project Costs</u>, determined according to the number of BPs involved, the overall project risk index, the economic value of the project.

It is clear that is not possible for all project proposals to involve all BPs (internal or external) to formulate a technical and economic bid. It will be up to the sensibility of the project manager, to decide who involve, according to the complexity indexes (ICI and ECI) and the BPs qualifications. At this stage, evaluations regarding the

availability of production capacity of each BPs must also be taken into account.
Finally, project manager will know, for each purchasing scenario, at least the following information:

- ✓ Project Risk Index
- ✓ Total Project Cost
- ✓ BPs involved

According to the well-known SWAT analysis (Leigh, 2009; Bertolini *et al.*, 2019), Project Risk Index and Total Project Cost can be plotted in a matrix graph where the x-axis shows the Project Risk Index, and the y-axis shows the Total Project Cost. The graph will identify 4 quadrants as shown in figure 1, in which the bottom left dial (e.g., Low Cost / Low Risk) is highlighted to indicate that it is obviously the quadrant in which to choose the preferable purchasing solutions.

TOTAL PROJECT COST	*HIGH*	High Cost Low Risk	High Cost High Risk
	LOW	**Low Cost Low Risk**	Low Cost High Risk
		LOW	*HIGH*
		PROJECT RISK INDEX	

Figure 1: project supply matrix scenario

Each step of the proposed approach is presented more in practice in the next section.

3.Case history

An industrial implementation of the proposed approach is therefore described in this section. This case history concerns an international company operating in the design and implementation of material handling and automated storage and retrieval systems (AS/RS). The company operates by assigning a project manager to each project from the initial stages of negotiations. The project manager works on the proposal phase, defining the most correct purchasing scenario for the specific project, involving in the analysis both external and internal business partners (or suppliers). The initial idea of our approach was therefore appreciated by the company, and many managers have been involved to help us in the definition of details and the collection of data.

3.1.Qualified business partners / purchasing group matrix

The first step is related to the definition of Business Partners (BP) / Purchasing Groups (PG) for the specific project. Note that with the term BP we consider both internal and external supplier.
The project manager, in cooperation with the other company functions (e.g. technical and purchasing functions), will break down the project under analysis, into purchasing group characterized by technical, production, logical and functional similar characteristics. The number and type of PGs must be standardised by project type, in order to historicise supplier behaviour in relation to the supply of a specific purchasing group. It is important that each purchasing group is described clearly and comprehensively and does not give rise to misinterpretation. Different PGs must be grouped into homogeneous Purchasing Categories (PC).
In this specific case, the company identified 21 different purchasing group for projects involving the implementation of AS/RS. The 21 purchasing group are clustered into 7 different purchasing categories. For example, the first purchasing categories is named *"rack"*, and includes purchasing group such as (i) design of racks, (ii) purchase of carpentry (ex-works finished product); (iii) profiling of tubes and metal profiles; (iv) bolts and nuts purchase, and others.
After the breakdown, the qualified business partners should be linked to the purchasing groups. The process of BP qualification (i.e. how to qualify a supplier and give it a grade with a score ranging, for example, from 1 to 100 or from 1 to 5) is not the subject of this study. Please refer to the extensive literature on the subject, such as De Boer et al., (2001).
If the supplier evaluation is generic (e.g., not specific for purchasing group), the project manager, assisted by the technical functions, must associate each supplier with a specific purchasing group (e.g. if the BP could supply that purchasing group, the value of the supplier's qualification is entered in the corresponding cell, otherwise the cell is left empty).
At the end of this step, a matrix similar to the one shown in table 1 will be obtained.

Purchasing Category - Purchasing Group			BUSINESS PARTNER				
			BP_1	...	BP_j	...	BP_m
	PC_1	PG_1	36		38		67
		PG_2			40		45
		PG_3			51		32
	PC_i	...	27				48
	PC_K	PG_j					24
		...					
		PG_n					51

Table 1: Business Partner / Purchasing Group matrix.

A value of 36 in the cross cell between PG_1 and BP_1 indicates that BP_1 could supply PG_1, with an overall supply quality rating (on a scale of 1-100, were the lowest value is for the worst BP and the contrary) of 36. At the same time, the absence of ratings in the BP_1 column, for example on the PG_2 and PG_3 rows, indicates that the supplier couldn't supply that specific purchasing group.

3.2.Intrinsic Complexity Index (ICI)

The second step to be carried out by the PM is to estimate the *Intrinsic Complexity Index (ICI)* of each PG and therefore that of the project. As above-mentioned, the ICI refers to the technical difficulty involved in the realisation of the products included in the purchasing group (e.g. difficulty in manufacturing activities, procurement and management by the business partner). The purpose of the assessment of ICI is to answer the question

"how difficult is the realisation (manufacture) of the components / products I order from the BP?".

The ability of the BP to deliver the supply on time-cost-quality should not be assessed here, as this assessment is already included in the BP assessment given by the matrix above).

To do this, an approach based on the TOPSIS (the reader can refer to Chen, 2000), a well know multi-attribute technique is suggested, whereby the following steps are taken. All PGs of a PC are selected and the criteria used to quantify their ICI are established for them. For example, in the case study, criteria such as:

(i) *intrinsic implementation difficulties*, linked to the realisation of the products by the purchasing group;
(ii) *technical specification complexity*, related to the difficulty of transferring the technical specifications to the BP;
(iii) *complexity of the supply chain for the BP* (i.e., how difficult is to source all production resources from the supplier);
(iv) *severity of regulations related to the design/manufacture of the item included in the purchasing group*

have been used in a TOPSIS determining for each purchasing group an *ICI index* on a scale from 1 to 5 (where 5 represents the maximum complexity).

3.3.Extrinsic Complexity Index (ECI)

In the same way as in the previous step, the project manager proceed to calculate the *Extrinsic Complexity Index (ECI)* of each PGs.

While intrinsic complexity is inherent in the intimate essence or nature of the purchasing group, extrinsic complexity does not concern the essence of the purchasing group. It assesses *the complexity of the management and implementation of the PGs in the project environment.* For example, in the case study, criteria such as

(i) *geographical complexity* of the location where the project is to be carried out (e.g., the risk indices related to earthquakes and hurricanes);
(ii) *geopolitical complexity* of the site where the work is to be carried out (e.g., restrictions on hiring local labour or restrictions on health and safety regulations on construction sites);
(iii) *tender restrictions and obligations* imposed by the customer;
(iv) *management complexity* related to the stakeholders involved.

have been used in a TOPSIS approach by determining an *ECI index* for each PG, on a scale of 1 to 5 (where 5 represents the maximum complexity).

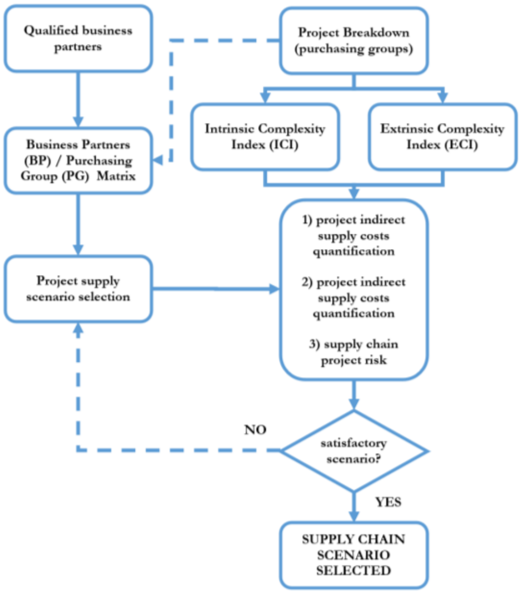

Figure 2: summary of procedure

3.4.Project supply scenario selection

As schematically shown in Figure 2, at this point the project manager has to procedure defining one or, better, more than one purchasing scenarios (e.g. deciding which and how many BPs to entrust the supply to). For example project manager could decide to engage

(i) one BP for all the purchasing categories;
(ii) different BPs for each purchasing categories or
(iii) different BPs for each purchasing groups.

Once the procurement scenario has been chosen, the direct costs must be calculated: if the BP is external, an offer must be requested from it, while if the BP is internal, the cost of carrying out the activity must be estimated.

Collecting all the direct costs, the project manager will obtain a matrix similar to the one shown in Table 2.

PURCHASE SCENARIO 1										
Nnumber of BP selected: 1 - BP_3 selected										
PURCHASING CATEGORIES		PURCHASING GROUP		ICI	ICE	BPq	ICIxICExBPq	DIRECT COSTS	
PC1	RACK	PG1	Design of racks	2	1	5	10	520.212 €	4,0%
		PG2	Carpentry (ex-works finished product)	3	4	5	60	1.098.781 €	8,4%
		PG3	Profiling of tubes and metal profiles	3	3	5	45	2.657.053 €	20,3%
		PG4	Bolts and nuts	4	4	5	80	123.529 €	0,9%

Table 2: case study project supply matrix scenario

In the table, for each purchasing group, it is reported:

(i) the Intrinsic Complexity Index (ICI), on a scale from 1 to 5 (where 5 represents the maximum complexity).
(ii) the Extrinsic Complexity Index (ECI), on a scale from 1 to 5 (where 5 represents the maximum complexity);
(iii) the qualification index for the selected BP (BPq), on a scale from 1 to 5 (where 5 is the worst BP and 1 is the best BP)
(iv) the product (ICIxECIxBPq), which represents, in an approach similar to that of the Risk Priority Number for FMECA (Bowles and Peláez, 1995), a synthetic risk index for that specific purchasing group;
(v) the total direct cost for the purchasing group;
(vi) the percentage of the direct cost of the purchasing group in relation to the total direct cost.

Once the purchase scenario matrix (Table 2) has been completed, the Total Project Cost and the Project Risk index will be determined.
Regarding the total project cost, it is given from the sum of three components of cost:

- the total direct supply cost;
- the field management direct cost;
- the field management indirect cost.

The total direct supply cost is nothing other than the sum of the direct costs of supply of every purchasing group. The field management direct and indirect costs pertains to the time spent from contractor and project manager in field management activities. The value could be determined with a diagram that brings back in the abscissas the number of BP involved and in the ordinates a percentage with which to increase the total direct supply cost. The development of the curve has been possible analysing the historical direct and indirect field costs of the contractor.
Note that these costs are an order of magnitude lower than the first. As an example, of a supply that has a total cost between 8,000,000 € and 15,000,000 €, and that involve 10 different BP, the field management direct cost is equal to 2.09% of supply chain cost.
Figure 3 reports an example of curve used to determine the field costs.

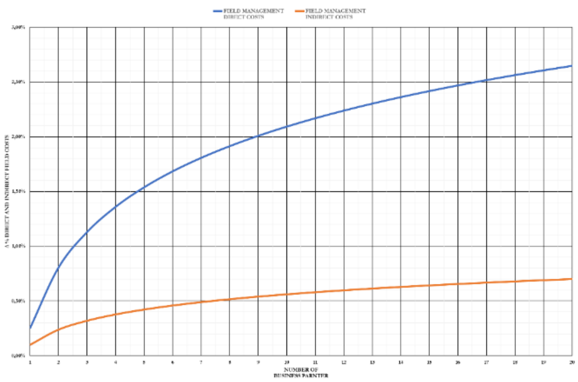

Figure 3: relationship between direct and indirect field costs and Business Partner number

Regarding the calculation of Project Risk, it will be determined as follows.
For each purchasing group, the project manager knows the risk index and the percentage incidence of the supply cost. The Project Risk is calculated as a weighted average of these values. Clearly, the higher the value, the higher the risk associated with the supply scenario.
At this point the project manager will be able to know, for each supply chain scenario (or purchasing scenario) summary information such as that reported in Figure 4, and he/she will have all information needed to choose the correct and more convenient scenario.

SUPPLY CHAIN SCENARIO 1	
NUMBER OF SUPPLIERS	**1**
PROJECT RISK	**46**
direct supply costs	13.595.735 €
direct field management cost	33.989 €
indirect field management cost	13.596 €
TOTAL COSTS	**13.643.320 €**

Figure 4: example summary sheet of a purchasing scenario

4.Discussion of results

For each of three possible purchasing scenarios which have been considered, the proposed approach allowed a good estimation of direct supply costs, as well as direct and indirect field management costs. Moreover, an index of risk has been identified. We are aware that the proposed model does not provide an answer, which, on the other hand, is supposed to be identified by the project manager doing a trade-off between risk and costs. The approach is also very sensible to the estimated costs written in the purchase scenario matrix, which especially in the case of field management costs are not always easy to find.

However, the proposed approach results easy-to-use, and provides a good overview of each possible scenario. As in our case, it can also be integrated in a web application, with the opportunity to store all the situations encountered over the years, keeping in memory which were the project conditions and which has been the output. This may result very helpful in the selection of purchase scenario for completely new projects or in case of newly hired project managers: looking at similar projects that took place in the past, the project manager would have a guideline and the support of a sort of backward planning.

5.Conclusion

This paper reports an operational methodology specifically designed to support the project manager in both the proposal and management phases. The proposed approach, if methodically carried out, allows the project manager to develop a matrix in which the possible procurement scenarios for a specific project can be compared in terms of (i) overall costs and (ii) overall risks. In this way, the project manager and the project team can consciously choose the business partners (e.g., internal and/or external suppliers) with whom to conduct a project, right from the proposal phase.

The methodological approach here presented has the peculiar and desired characteristic to be "easy-to-use", and we are aware it might be improved in many different ways. To the authors best knowledge and experience, the following future perspectives seem promising:

(i) integration of aspects concerning the project breakdown structure into the identification of purchasing groups;

(ii) consideration of the project critical path in the estimation of the risks;

(iii) consideration of the BPs availability during the project time horizon.

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