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A Strategic Location Model of Stationary Production Units: A Case study in the Albacora Leste field

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Abstract — *The imminent interest in issues related to the oil and gas sector has always proved to be a profitable source of investment and research, with incremental gains and innovations in the various sectors of the offshore industry. Particularly in the context of resource localization, the adoption of mathematical models presents itself as a challenging theme. In this context, the research has the purpose of proposing a localization model of Stationary Production Units (SPU) of an oilfield located in the Campos Basin, Rio de Janeiro (Brazil). The computational tests were conducted using the Lingo software, based on data from the Albacora Leste field. The results of the proposed model demonstrated a reduction of approximately 12% in the configuration costs, compared to the current location.*

Keywords— Location of Facilities, Stationary Units of Oil and Gas Production, Mathematical Programming.

I. INTRODUCTION

Considered a strategic aspect for most companies, the layout of the distribution system plays an important role in the productive scenario. The resource location problem covers core topics of the distribution system design. In the Oil and Gas (O&G) sector, there is a growing search for methods that optimize the distribution of products or services.

Particularly in the scope of resource localization, numerous researches have been conducted in order to treat the theme from the perspective of optimization, as observed in the works of Figueira (2014); Ignacio; Sampaio (2012); Rosa (2006); Souza (2011).

The location of equipments and production units is one of the main problems in oil industry projects. The choice of the system and the geographic location of the system are extremely important to obtain the planned results and maintenance of the operation of the plant. Given this, a series of mathematical programming models were proposed in order to solve the problem of finding platforms and multi-skilled facilities (IGNACIO; SAMPAIO, 2012).

With a focus on minimizing investment costs, we mention the works of Hansen; De Luna Pedrosa Filho; Carneiro Ribeiro (1992). Frair; Devine (1975) proposed a model to locate the SPU, or platform, according to the oil flow over time, seeking to maximize the net present value (NPV). The development of a model to minimize the investment costs, considering the location, capacity and amount of production of the platforms, was object of study of Devine; Lesso (1972). However, a broader analysis of the applicability of such models can be observed in Galvão; Acosta Espejo; Boffey (2002). These authors state that because there is no single model that

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optimizes the system globally, it is appropriate to adopt a hierarchical model, in order to avoid partial optimization of the system. An interesting fact is that none of these models consider fields not equipped with manifolds, which is a reality of the systems that were currently found.

Another problem encountered in the oil and gas sector, with regard to the location of equipment and SPUs is similar to the location of facilities of onshore companies (ROSA, 2006). Equivalence is explained by Devine; Lesso, 1972, who makes a parallel between inputs from the traditional productive sector and O&G. These authors affirm that the costs are directly proportional to the extension of the pipelines, to the place where the platform is allocated and the capacity of the platform. For this reason, the optimization of the submarine layout tends to improve the costs of the production line and the flow, as the location of the SPU is optimized.

In this scenario, we intend to perform an analysis of the current location of equipments and SPUs of an oil field in the Basin in Campos, with a view to proposing a localization model based on the hierarchical model of Ignacio; Sampaio (2012). In this way, we seek to investigate the hypothesis of cost optimization through the geographical reallocation of SPU in the field of Albacora Leste using mathematical models of operational research.

For the development of the mathematical model, it is of paramount importance to familiarize ourselves with the main aspects that make up the original model to be adapted. Theory considered important in relation to what is proposed in this project, the analysis of concepts and term relationships, such as oil wellheads, Manifolds, pipelines connecting wells and equipment, as well as SPU, were based on the work of Thomas (2004). In addition, given the similarity with the issue treated and the domain of the problem, which include specific oil and gas exploration devices and the hierarchical operational search localization models, the studies conducted by Cercaira (2005); Ignacio, Sampaio (2006) were valuable sources of knowledge in conducting the research.

Besides that, the hierarchical model of operational research described in Ignacio; Sampaio (2012) will be presented, since it will serve as the basis for the generation of the new model.

The experiments were conducted using actual data obtained from the National Petroleum Agency (ANP) (ANP, 2016), except for costs that are fictitious data. The use of real data approximates the reality model, considering the actual and proper geographic location for comparison with the data of the studied oilfield.

For the implementation of the model, we chose to use LINGO® software, version 10.0, belonging to LINDO Systems Inc®. Its adoption is justified by the ease of use and efficiency for solving linear and non-linear problems (BA; PRINS; PRODHON, 2016).

The optimal location results will be presented through tools of geographic information systems. In order to locate geographically the equipment and items of the oilfield, from the real data and calculated by the model, the software used was Google Earth.

The numerical results of the proposed model will be compared with the real location of the SPUs, with the aim of improving the efficiency of the system under the hypothesis of optimization through the geographic repositioning of the said production unit.

II. MATERIALS AND METHODS

2.1 Oil Field Projects

Planning facilities and submarine layout, known as the location of wells, platforms and pipelines of the project, can reduce costs, improve flow and optimize production. Currently, there are hierarchical localization models that propose to solve these problems. It should be noted that the intention is to locate the platform in an interconnected way to systems not equipped with manifolds.

Fig. 1 exemplifies a production system and the equipment to be located. The illustration shows the location of the wellheads, the point of the oil well where the oil is extracted. The equipment responsible for concentrating the oil and sending the platform is called a manifold, which may still have other functionalities. The ducts are responsible for transporting the fluid between the equipment. The SPUs are responsible for receiving the oil extracted from the wells for storage or sent to the refineries, concentration tanks or the manifolds to be injected.

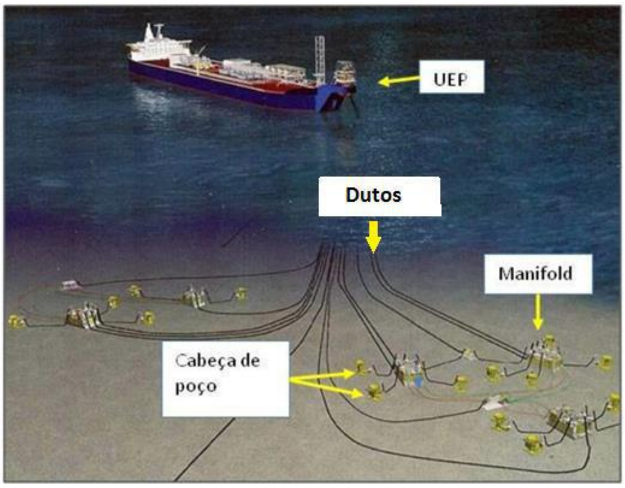

Fig.1:Underwater production system (SPU, manifold and wellhead)

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Among the terminology of the constituent elements of an underwater production system (Fig. 1), the term "well head" can be defined as the location of the soil where drilling is started and where equipment for reservoir exploration and production flow will be installed (IGNACIO; SAMPAIO, 2012). The manifolds are equipment that serve to collect the flow coming from several points, gathering in a duct or set of ducts, or distributing the flow coming from a point (LIMA, 2007). They can be production, water and gas injection, gas lift, gas control and export. In short, they are a large set of valves of great complexity, responsible for receiving the oil and/or gas from one or more wells and directing the flow, or distributing, it to the SPUs. In addition, they may receive the flow of fluid or gas directed by the UEPs in order to inject it into the well.

The movement of fluids that will go to production or reinjection in oil fields is done through submarine pipelines. In the case of production, there is a flow of oil and gas from the wells, through the equipment, to the SPU and in the injection there is the reverse flow, from the SPU to the various equipments and consequently to the well (THOMAS, 2004).

According to Rosa (2006), a SPU can be understood as an industrial unit on the high seas, with characteristic functions such as separation of oil, gas and water, with the task of treating them so as to enable the unification of the elements for export of oil and gas, and the disposal of water. These units when allocated to a well can be anchored or in dynamic positioning, allowing the reception of production and insertion of fluids in the formation. The transportation of the materials to be exported can take place through oil pipelines or relief ships in the case of oil and gas pipelines for compressed gas. According to Ignacio, Sampaio (2012), the elements considered to design a SPU are: expected production, sea depth and environmental characteristics.

2.2 Hierarchical localization model

A hierarchical model can be characterized by a set of interrelated variables that relate to the location of a given facility and the respective allocations.

According to Ignacio and Sampaio (2012), the problem of locating SPU allocated to manifolds, which in turn are allocated to heads of oil wells, are solved by means of discrete models. That is, for a set of wellheads with a predefined location, a set of possible manifold locations must be allocated, which in turn must be allocated to a set of possible SPU locations. Finally, the model should generate the optimal location for this set of "possible locations" previously proposed, with the main objective of minimizing the total costs, from the fixed costs of installation of each equipment. Fig. 2 shows the previously described system.

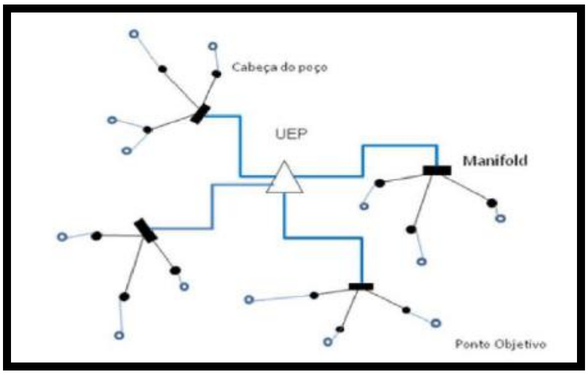

Fig.2: Schematic plant of an underwater field.

The following mathematical model presents the set of parameters and restrictions elaborated for the hierarchical problem presented by Ignacio and Sampaio (2012).

Indexes:

- i: Defines the set of possible locations of well heads;
- j: Defines the set of possible locations of n Manifold;
- k: Defines the set of possible SPU locations.

Parameters:

- $a_j^1 =$ Cost of using a unit capacity of a Manifold;
- $a_k^2 =$ Cost of using a unit of SPU capacity;
- $c_{ij}^1 =$ Cost of connecting the wellhead i to the Manifold j,i=1,2,..m,j=1,2,..n;
- $c_{jk}^2 =$ Cost of connecting the Manifold j to UEP k,j=1,2,..n,k=1,2,..l;
- $f_j^1 =$ Fixed cost of installing a Manifold, on site j,j=1,2,..n;
- $f_j^2 =$ Fixed cost of installing a SPU, on site k, k=1, 2,...l;

Parameters of Capacity:

- $K_j^1 =$ Manifold Capacity j,j=1,2,..n;
- $K_j^2 =$ UFP Capacity k,k=1,2,..l;
- *M* = large number that can be defined as: *M* = *max*{ $K_k^2, \forall k$ }

Parameters / Demand variables

- d_{ij} = demand parameter of wellhead i, when allocated to Manifold j, i=1, 2,..m, j=1, 2,..n;
- w_{jk} = Variable of the amount of processing demand of Manifold j, allocated to UEP k, j=1, 2,...n, k=1, 2,...l;

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Location and allocation decision variables:

- $x_{ij}^1 = \begin{cases} 1, \text{Se a cabeça de poço I está ligada ao manifold j,} \\ 0, \text{Caso contrário.} \end{cases}$
- $x_{jk}^2 = \begin{cases} 1, \text{Se o manifold é localizado em j,} \\ 0, \text{Caso contrário.} \end{cases}$
- $y_j^1 = \begin{cases} 1, \text{Se o manifold é localizado em j,} \\ 0, \text{Caso contrário.} \end{cases}$
- $y_k^2 = \begin{cases} 1, \text{Se a UEP é localizado em k,} \\ 0, \text{Caso contrário.} \end{cases}$

Three components are responsible for the costs of a plant, they are: fixed costs of implementation of interconnection devices, variables of connection costs and processing costs of each device. Interconnection devices have limitations, which result in a cost defined as the cost of processing the oil flow.

Model:

$$Min\ Z = \sum_{i=1}^{m}\sum_{j=1}^{n} c_{ij}^1 x_{ij}^1 + \sum_{j=1}^{n}\sum_{k=1}^{l} c_{jk}^2 x_{jk}^2 + \sum_{i=1}^{m}\sum_{j=1}^{n} a_j^1 d_{ij} x_{ij}^1 + \sum_{j=1}^{n} f_j^1 y_j^1 + \sum_{k=1}^{l} f_k^2 y_k^2 \quad (1)$$

Subject to:

$$\sum_{j=1}^{n} x_{ij}^1 = 1, \forall i \quad (2)$$

$$\sum_{i=1}^{m} d_{ij} x_{ij}^1 \leq K_j^1 y_j^1, \forall j \quad (3)$$

$$\sum_{i=1}^{m} d_{ij} x_{ij}^1 = \sum_{k=1}^{l} w_{jk}, \forall j \quad (4)$$

$$\sum_{j=1}^{n} w_{jk} \leq K_k^2 y_k^2, \forall k \quad (5)$$

$$w_{jk} \leq M x_{jk}^2, \forall j, k \quad (6)$$

$$\sum_{k=1}^{l} x_{jk}^2 \leq 1, \forall j \quad (7)$$

$$x_{ij}^1, x_{jk}^2, y_j^1, y_k^2 \in \{0,1\}, \forall\ i, j, k \quad (8)$$

$$w_{jk} \geq 0, \forall\ j, k \quad (9)$$

Template settings:

- For the objective function (1): The first and second components represent the costs of connecting the heads of wells and the manifolds (at the first level) and between the manifolds and SPUs (at the second level), respectively. The third and fourth components represent the manifold operating costs, which are directly related to the quantity of oil processed at level 1 and the SPU at level 2. Finally, the manifold and SPU installation costs are expressed in the fifth and sixth components.
- Restriction (2): Requires each wellhead to connect to at least one manifold;
- Constraint (3): Represents the processing capacity limitations of a manifold;
- Restriction (4): Ensures that each manifold will have a balance in the flow of production;
- Restriction (5): Represents the limitations of SPU's processing capacity;
- Constraint (6) together with (5): Ensures that there will be a connection between a SPU and a manifold if, and only if, a SPU k is installed and servicing a manifold j;
- Constraint (7) together with (5): Require an open manifold to be allocated to a single SPU;
- Restriction (8): Guarantees the binary nature of decision variables;
- Restriction (9): Ensures non-negativity of processing demand variables.

III. PROPOSED MODEL

From the previous data and studies carried out on the national oil fields, which were made possible through ANP data, it was verified that not all of them have the configuration that meets the requirements of the model proposed by Ignacio and Sampaio (2012) aa. A configuration found constantly and with a certain naturalness is the absence of manifolds. According to data from the ANP, the relationship from the exit of the oil to the SPU can occur directly, that is, in a simplified way, risers connect the wellhead directly to the SPU, absent the flow control system, as well as shown in Fig. 3, which exemplifies the field to be treated in this work, the East Albacore Field.

IV. ADAPTATION AND MODEL GENERATION

From the need presented and the study of the model shown, it was concluded that a new model must be generated to meet these specific systems.

This new model was adapted to field configuration without the equipment known as manifold, which will portray a modification in structure and modeling as a whole. Among the main influencers of this new model are:

- Coordinates of the wells that connect to SPU and their depths;
- Maximum number of wells by SPU;
- Minimum number of wells to be connected to the SPU, according to the project;
- Installation bundle of each wellhead to SPU.

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From the collection of this information, one must follow the next steps in order to minimize the costs of implementing the system:

- SPU co-ordinates with associated wells;
- Coordinates of wellheads.

The resolution of this type of problem must occur in stages, being the first one, to delimit the amount of SPU's that will act in the oil field. The second step is to locate all well heads, and finally locate the SPU. The treatment of this problem must be done through subproblems, whose solution results in a fixed parameter, which will serve as input for solving another subproblem. This type of treatment does not guarantee the optimization of the system, as it does not result in a global optimum model, but a hierarchical localization model contributes to the construction of a more integrated model, which reduces the partial optimization of the system (GALVÃO; ACOSTA ESPEJO; BOFFEY, 2002).

From these considerations, an adaptation of the model of Ignacio and Sampaio (2012) was developed for oil fields with only wellheads and SPUs. The model is shown below.

Indexes:

- i: Defines the set of possible locations of n well heads;
- j: Defines the set of possible locations of m SPUs.

Cost Parameters:

- c_{ij}: Cost of connecting well i to a SPU located at location j;
- vj: Fixed cost of establishing a SPU in place j;

Capacity Parameters:

- a_{ij}: Capacity of SPU j to support well i, when allocated to such SPU;
- b_j: Maximum SPU capacity that can be installed at location j;

Demand Parameters:

- p: Maximum number of facilities that can be installed;

Decision variables:

In terms of the above notation the problem can be formulated as:

$$Min\ Z = \sum_{i=1}^{n}\sum_{j=1}^{m} c_{ij}x_{ij} + \sum_{j=1}^{m} v_j y_j \qquad (10)$$

Sujeito a

$$\sum_{j=1}^{m} x_{ij} = 1, \forall i = 1, \dots, n \qquad (11)$$

$$\sum_{i=1}^{n} y_j \leq p \qquad (12)$$

$$\sum_{i=1}^{n} a_{ij}x_{ij} \leq b_j, \forall j = 1, \dots, m \qquad (13)$$

$$x_{ij} - y_j \leq 0, \forall i = 1, \dots, n; j = 1, \dots, m \qquad (14)$$

$$x_{ij}, y_j \in \{0,1\}, i = 1, \dots, n; j = 1, \dots, m \qquad (15)$$

Template settings:

- Regarding the objective function (10): The first component of the objective function represents the interconnection costs, while the second captures the installation costs of the SPUs which is assumed fixed independent of the size of the same.
- Constraint (11): Ensures that each well is connected to exactly one SPU.
- Constraint (12): Limits the number of SPU 's in the solution at p.
- Restriction (13): They express the capacity limitations of SPUs.
- Restriction (14): Ensures that the wells are only allocated to locations where SPUs exist.
- Constraint (15): Expresses the binary nature of the decision variables.

V. RESULTS AND DISCUSSIONS

For the application of the proposed model we used the data from the Albacora Leste field. For these non-real data (costs) care was taken to exemplify reality in the best possible way, adding well-sized values to the variables.

Using real data from the Albacora Leste field, it is assumed that the optimal quantity of SPUs for the field and the capacity of the field is already defined. The intention will be to flow from the wells to the amount close to the maximum, which is according to surveys done at the ANP. It is worth mentioning that the model would be able to choose between SPUs of different capacities to service the oilfield.

Data on the location of the oil wells were found in the ANP (ANP, 2016) database, as well as its depth and water depth, important information about the field under study, which helps to understand the use of some equipment, such as Local SPU, for example.

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To locate the data geographically, and from that, to find the approximate distances between the elements was used the Google Earth software, based on the locality of Farol de São Thomé. The choice of this location based on the distances of the installation costs was based on the location of the Geographic Field, the influence of the site for the offshore operations and the easy knowledge of both the academic part and the localization software. This point will serve as a basis to find the data of platform implantation cost in the oilfield.

Implementation according to the original location

The actual field configuration is illustrated in Fig. 4, which shows the actual location of the well heads (represented by the circles) and the SPU P50 (symbolized by the triangle) for the Albacore Leste field. Due to space limitations, the geographical coordinates of the elements of said field will not be presented, nor will the results generated by the model given its great dimensionality.

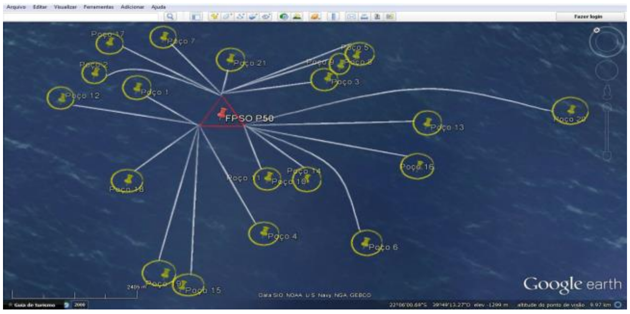

Fig.3: Actual field configuration of Albacora leste.

The implementation of these fixed coordinates in Lingo® resulted in an objective function of the order of R$ 2.164800,00, which represents the total cost amount.

VI. IMPLEMENTATION ACCORDING TO THE MODEL PROPOSAL

The configuration proposed by this methodology finds SPU P50 in a new geographical coordinate, which tends to optimize costs and improve the production flow. The new configuration proposed after implementing the model in the LINGO® tool can be seen in Fig. 4.

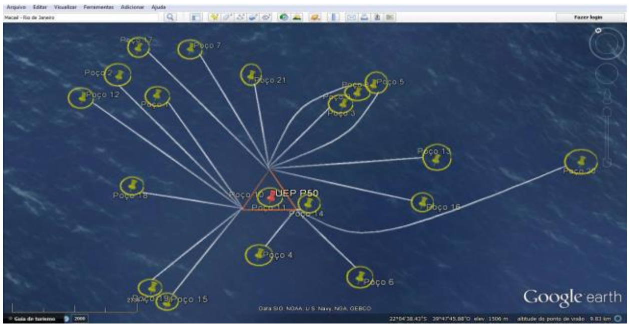

Fig.4: Location proposed by the model.

The model implementation in Lingo® was a new geographic location for a SPU and a total cost value of R$ 1.905.360,00, represented through its objective function.

VII. FINAL CONSIDERATIONS

The result obtained from the implementation of the model provides the analysis of project costs used in the Albacora Leste oilfield. Even with the use of some fictitious sources they remain identical for both cases, which does not influence the output data of the model.

The result of the original configuration of the field was R$ 2.164.800,00 while the costs of the new configuration, according to LINGO®, were R$ 1.905.360,00, resulting in a decrease in expenses of R$ 259.440,00, approximately 12% savings. It is a considerably high value, however, which cannot be taken as the real value that would be saved by using fictitious cost data in the model.

The analysis of the obtained results proves the validity of the model and the capacity of this methodology to improve the allocation of resources in the oil fields, better allocating the facilities and dimensioning the equipment, which allows to reduce expenses not only in certain equipment, but in any system of production.

The generated model suffers considerable influence of the costs of each variable of the system, with this it is valid to emphasize that the implementation of real data tends to improve the resolution of the problem.

The proposed model showed robustness in the optimization of the SPU's location, even when implemented a mixture of real and fictitious data, the percentage gains analyzed validate its proposition and show what can be done in the current fields and future projects. The intention of today's industries and companies from diverse sectors is to generate innovative systems that provide exactly what this model of operational research has determined: competitive advantages, profits and focused investments.

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