OIL RIG FLEET DIMENSIONING: A STRATEGIC DECISION USING REAL OPTIONS

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ABSTRACT

The oil drilling activity is complex, involving onshore and offshore units, for perforation and production, of great or small size and with extremely varying degrees of technological complexity. It is a risk business due to work with high costs and remuneration highly variable in time, function of market conditions (oil barrel price and availability of equivalent rigs). Also, it has significant weight in the composition of exploitation and development costs of a field.

The Real Options Theory considers the technical and economic uncertainty, the flexibility in the managerial decision-making, the irreversibility (total or partial) of investments and the waiting value, that is, to wait for better conditions or new information.

This work presents a study for the oil drilling rig owner to decide among options (operation, temporary suspension, exit from the business) function of freight charge values (day rate). Operational, acquisition, suspension, maintenance, reactivation and abandonment costs are considered; and also, volatility, dividend rates and capital attractiveness rates.

Thus, it is possible to determine the adequate composition of the oil drilling rig fleet, departing from the determination of day-rate ranges for each type of drilling rig and to make an optimum decision (abandonment, temporary suspension, operation, reactivation or reentry/expansion).

It is reached the most adequate rig fleet composition, from the determination of the optimal switches - the threshold points - among the alternatives (entry, operation, suspension, exit, reactivation) and the correspondent day-rate intervals to each rig type. Two sets of complex partial differential equations are generated to represent the policy options and general conditions and they are solved by numerical methods. Finally a sensitivity analysis is performed varying the values of the previous deterministic variables and showing their effect on both the optimal decision rule and the value of rig considering the embedded options.

Keywords: Real Options, Petroleum, Drilling, Rig.

1 – Introduction

The oil drilling activity is basically the leasing of a drilling rig from a petroleum company (or its representative) and its operation for petroleum prospect and production.

The drilling rig operation is complex, involving onshore and offshore units, for drilling or production, of great or small size and with extremely varying degrees of technological complexity. The cost per day of a drilling rig (the day-rate) varies a lot along time, as a function of market conditions dictated by oil barrel price and of its type or category. Complementary factors are cost variation for raw materials and for manpower, regulatory rules (safety, environment, certification) and partnership formation.

A drilling operator company acquires or constructs a unit and, in general, receives a day-rate remuneration from the oil company which uses the rig. In some cases receives an incentive bonus for operational performance or low equipments unavailability. Also, there are turn-key contracts in which a fixed value is received for a well drilling, independent of the duration; but its application is more restrictive, because it can lead to priority in operation speed and not in well quality.

The remuneration value is affected by economic uncertainty (motion of market influence factors) or by technical uncertainty (new technologies, obsolescence, new contract types and performance of newly-installed equipments). The drilling rig is depreciated by use and by maintenance needing; and the technological development renders it less competitive. Therefore, total return can be reduced by lease day-rate fall or by rig productive useful life decrease.

The volatility of day-rate along time is very high, suggesting that economic evaluations based in NPV (net present value) are inadequate. It is as serious as greater the values involved and the importance of decision. Thus, the companies support periods of negative cash flow in expectation of the situation reversal, as they know that the exit – and an eventual comeback – has a cost; and prevents (or makes difficult) realization of future profits in case of market recovery. However, it is usual that the nearer the end of rig useful life, the smaller the tendency to support such losses.

In general the rig operating cost presents a behavior nearly constant, since asset depreciation is a very significant part. Even for onshore rigs, where manpower cost has greater weight, the operating cost does not vary too much at short or medium term, since the market is local and less globalize. In Brazil the strongest effect has been the exchange rate variation, as occurred in the beginning of 1999, as the Real (Brazilian currency) had a devaluation in relation to dollar, reducing manpower cost comparing to international standards.

As rig day-rate is extremely variable, the rig ownership is economically very interesting in periods of high demand; this is decreased by market cooling off and fall of current rates. Thus, decisions about drilling rig acquisition or its sale, operation interruption or reactivation, must be preceded by detailed and dedicated study, considering managerial options and available time to exercise those options, avoiding inopportune attitudes, almost always irreversible ones.

2 – Model for Operation, Temporary Stop and Abandonment

The Theory of Real Options, though recent, presents large quantity of studies for the petroleum industry (Dias, 1999), mainly for the determination of economic viability of producing fields and for proposals in biddings for exploration areas (Paddock & Siegel & Smith, 1998). However, in the drilling sector few works are available.

In the eighties, a study was realized about Chilean copper mine exploitation (Brennan & Schwartz, 1985), considering options of activity, temporary suspension and definitive abandonment. Following this, Dixit & Pindyck (1994) had developed a very complete model that will be adapted for this study of rigs, considering the costs from these movements.

It is assumed that drilling activity is as an American option – can be exercised at any time until its expiration – with dividend payments and that can be interrupted temporarily or totally at any time. And this interruption may be reverted – with reentry or reactivation at any moment – even with losses as: qualification (technical excellence dissolves very quickly when it is not continuously exercised), teams, customer loyalty, image and prestige in the market or inside the community and equipment scrapping.

In this continuous process model the costs are deterministic and the return is function of two variables: the stochastic one represented by value of the rig freighting charge (P) and the discrete one indicating actual state of the rig. The addition of new stochastic variables would augment much the model complexity without an equivalent improvement in the results accuracy.

Variable P is modeled by a Geometric Brownian Motion. The selection of this method is function of the limited useful life of the rigs (in the range of 20 to 30 years) and of continuous technological innovations generating obsolescence (state-of-the-art floating units are relatively recent). As historical series of more than 30 years would not be obtained, the utilization of the Mean-Reverting Process (MRP) would not aggregate value, besides to introduce a greater degree of complexity (hyper geometrical functions with infinite series).

The fluctuation of price P is represented by the Contingent Claims Method, since the rig leasing market is sufficiently complete and this method does not require calculation of an exogenous discount rate adjusted to the risk. In any way the use of Dynamic Programming would be equivalent if neutral evaluation to risk were used (Dixit & Pindyck, 1994).

A flag defines actual rig state: 0 (inactivity, the rig was sold, disposed or is without conditions for utilization), 1 (rig in activity or available for operation) or m (rig temporarily stopped and waiting for better market conditions).

For each state the associated opportunity values are defined. Then:

$V_0(P)$ = Value of the option to invest, being not in activity (idle);

$V_1(P)$ = Value of the operation profit (or loss) plus the value of option to interrupt or leave the activity;

$V_M(P)$ = Value of the option to reactivate or to abandon, being temporarily stopped;

Four threshold values are operated corresponding to boundary regions for the type of attitude to take. They are: P_L, P_M, P_R and P_H, where $0< P_L <P_M <P_R <P_H < \infty$. In some special conditions two of these consecutive values may be equal.

P_L represents abandonment value, so low that when reached it suggests the complete exit from activity, since recovery probability is minimum. It is the trigger in which exercise of abandonment option is optimum.

P_M is the threshold for temporary stopping option and indicates that the activity shall be discontinued due to its low value, but interruption shall be temporary, waiting for possible changes that conduct to a comeback.

P_R is the threshold for reactivation option, higher than P_M, and points to an activity recovery, in case the rig is temporarily stopped; however it is not sufficiently high to justify an entry (or reentry) in business, if the rig is no more available.

Now, P_H is the threshold for the investment option or for reentry, a so attractive value that it is interesting a reentry (or comeback) in business, or even the expansion for who is in the business, since demand conditions and capacity are adequate and justify the sale or construction of a new rig.

In this way, these four values define 5 zones of attitudes, as shown in Figure 1. Zone I corresponds to abandon the activity; in the zone II the rig is stopped, but ownership is maintained and there are conditions to put it in operation (reactivation).

Zone III is called the hysteresis zone in which current state is maintained because the value of the stochastic variable is not enough for an attitude change: it is not so high to justify a rig stopping, nor so low to indicate an interruption to an operating rig. Zones IV and V show rigs in activity: in the latter an entry or an expansion is possible, while in the former the reactivation is only justified for a temporary stopped unit.

Cost-related variables of rigs used in the model are:

– P = Rig day-rate;
– I = Acquisition (or construction) cost of a new rig;
– C = Rig operational cost;
– EM = Immediate cost (lump-sun) of temporary suspension of the rig;
– R = Immediate reactivation cost (lump-sun) of the temporary stopped rig;
– M = Maintenance or conservation cost of the temporary stopped rig;
– ES = Immediate abandon activity cost (lump-sun) to, being the rig temporarily stopped;
– E = Immediate abandon cost lump-sun), being the rig in activity.

Those variables present a known and constant cost, in which P, C and M are expressed in million of dollars per year and the others in millions of dollars.

Also the following variables are employed:

– V(P) = Value of the investment project (in millions of dollars);
– r = Risk-free discount rate, real and after taxes (in % per year);
– σ = Volatility, standard deviation of the rate of stochastic variable P by unit of time (in % per year);

– δ = Convenience rate, measure of the benefit generated by the operating rig. It can be interpreted as a dividend rate; ratio between net cash flow (freight charge minus operation cost and minus taxes) and the rig market value; or, alternatively, as the net discount rate, that is function of attractiveness rate (or the money opportunity cost) required for the investment risk, calculated by: $\delta = \mu - \alpha$.

Several considerations shall be made about interdependence of variables, as follows:

– Reactivation cost shall be smaller than a new rig acquisition cost (R < I), or the temporary stop should not occur; the same reasoning for relationship between maintenance cost and operational cost (M < C);

– In the P variable is built-in the utilization expectation during a year. Thus, if the day rate is US$ 100,000 and is expected that the rig spends 45 days without operation – due to repairs, improvements or lack of demand – P will be US$ 32,000,000 /year;

– The passage from the active state to the exit may be direct (cost E) or by stages (cost EM + ES); then, E = EM + ES;

– The variable E can present negative value, if there is residual value for the unit sale, which is superior to exit expenditures, which is common in rigs. This should mean that the cost is not sunk, that is, the investment would not be totally irreversible, but presenting alternative use;

– In any way, E + I > 0, or we would have a “perpetual machine to make money”, where we would enter in the business only for the profit to exit, and this process would be indefinitely repeated (“arbitration”). In other words, the acquisition cost of a new rig cannot be smaller than the sale price of a used rig, with same characteristics and in the same instant;

– The variables EM and M are inversely correlated, a greater value for one variable implies in a smaller value for the other. To interrupt activity, there are costs of labor indemnities, breach of contracts and legal liabilities in relation to environmental and safety conditions. The higher is the immediate cost EM, the smaller will be continuous maintenance cost M;

– In general, a personnel is an item of heavy economic impact in a suspension. There are 3 hypothesis: employees dismissal with payment of all labor rights (including fine of 40% on the Worker’s Guarantee Fund); indemnity over the due additional amounts and alteration to administrative work with lower remuneration; and keeping all rights and payments (in the expectance that would be a short duration stop). These conditions present decreasing order of values for EM, but increasing order for M (respectively near-zero cost, partial cost and total cost);

– The values of EM and M depend on stopping time interval and on magnitude of corresponding costs. If reactivation is soon expected, it should be interesting to keep the team, reducing only costs related to transport, hotel and eventual services: it is the so-called mothballed state. Now for the opposed case we have the cold stacked state, corresponding to a low prospect of soon comeback, with minimum maintenance, removal of majority of the team and almost total stoppage of service and supporting contracts;

- Variables M and R are also related. A smaller cost M (personnel dismissal, little attention to conservation of unit operating conditions, cannibalization and rig deterioration) will imply in a higher reactivation cost and vice-versa;
- Variable R also depends on necessary requisites for new actuation stage. If previous conditions are maintained R can have a very low value; however, if the new demand require conversions and additional equipments R may be significantly higher;
- As the useful life of rigs is superior to 20 years, it can be considered as a perpetual option ($\tau = \infty$);
- Discount rates for revenues and costs are not necessarily equal, since cash flows have different risks;
- Total return from an asset (μ), for example Petrobras stocks, is the sum of capital gains (valuation/devaluation) plus distributed dividends. In the case of asset "drilling rig", a warm period in the market increases the asset value (capital gains for the rig owner) and also this asset distributes dividends in the form of cash flow from freightage;
- Return generated by rig freight charge increases at a rate α, and due to associated risk, it is discounted by the rate adjusted to the risk μ. Thus, present value is obtained by: $\int_0^\infty P.e^{\alpha t}.e^{-\mu t} = P / (\mu - \alpha) = P / \delta$;
- Operational cost is constant and discounted by risk-free rate r. Its present value is given by: C/r;
- When we pass to the suspension state, we cannot determine a priori what will be the time interval (may become definitive) and the present value of the conservation cost is obtained by: M/r;
- When we pass from temporary suspension to reactivation, there is a marginal cost which present value and is given by: (C – M)/r;
- There is no time interval between option exercise (abandonment, suspension, reactivation, entry) and corresponding cash flow. Consequences are immediate, without waiting time or deferments;
- It is not considered obsolescence during the rig useful life. If it were threshold P_H and P_L would be increased by a factor due to this depreciative effect.

3 – Mathematical Modeling

The three current states for the rig (0, m, 1) can be represented from optimization equations by Contingent Claims method (Dixit & Pindyck, 1994).

For each state a partial differential equation is obtained that has a general solution composed by terms representing possible opportunities and adequate boundary conditions. The terms contain constants to be determined (A_1, A_2...) and quadratic equation roots (β_1 positive, β_2 negative) that represent stochastic variable modeling. Those roots are calculated by:

$$\beta_1 = ½ - (r - \delta) / \sigma^2 + \sqrt{w} \tag{1}$$

and

$$\beta_2 = ½ - (r - \delta) / \sigma^2 - \sqrt{w} \tag{2}$$

where

$$w = [(r - \delta) / \sigma^2 - ½]^2 + 2 . r / \sigma^2 \tag{3}$$

and

$$\beta_1 > 1, \beta_2 < 0, r > 0, \delta > 0.$$

For state 0 (idle) that occurs in the interval $[0, P_H]$ we have:

$$½ . \sigma^2 . P^2. V_0'' (P) + (r - \delta) . P . V_0'(P) – r . V_0(P) = 0 \tag{4}$$

The general solution is:

$$V_0(P) = A_1 . P^{\beta 1} + A_2 . P^{\beta 2} \tag{5}$$

where the terms represent option to enter in activity. As in the inferior limit 0 the option value tends to be null (absorbent barrier) it is demonstrated that A_2 (corresponding to negative root β_2) is also null and the solution is reduced to:

$$V_0(P) = A_1 . P^{\beta 1} \tag{6}$$

For state 1 (active) that occurs in the interval $[P_L, \infty]$ we add to previous differential equation a term corresponding to cash flow due to the actuation, then:

$$½ . \sigma^2 . P^2 . V_1'' (P) + (r - \delta) . P . V_1'(P) – r . V_1(P) + (P – C) = 0 .. \tag{7}$$

The general solution is:

$$V_1(P) = B_1 . P^{\beta 1} + B_2 . P^{\beta 2} + (P/\delta) – (C/r) \tag{8}$$

where the first term corresponds to the abandonment option, the second to stop temporarily and the last two terms for keeping activity. As in the superior limit ∞ the abandonment option value tends to be null, B_1 (corresponding to positive root β_1) goes to 0 and the solution is restricted to:

$$V_1(P) = B_2 . P^{\beta 2} + (P/\delta) – (C/r) \tag{9}$$

For state m (lay-up) that occurs in the interval $[P_L, P_R]$ the differential equation receives a term corresponding to the maintenance cost, as follows:

$$½ . \sigma^2 . P^2 . V_m'' (P) + (r - \delta) . P . V_m'(P) – r . V_m(P) – M = 0 \tag{10}$$

The general solution is:

$$V_m(P) = D_1 . P^{\beta 1} + D_2 . P^{\beta 2} – (M/r) \tag{11}$$

where first term corresponds to the option to reactivate, second to abandon and last term to remain suspended temporarily. As limits are intermediary regions no term can be eliminated.

In the four boundary terms occur the alterations of activity state. As we have 3 states (n), theoretically can occur n. (n – 1) = 6 changing points.

In P_H we pass from state 0 to 1 at a cost I.

In P_R we pass from state m to 1 at a cost R.

In P_M we pass from state 1 to m at a cost EM.

In P_L we pass from state m to 0 at a cost ES; or from state 1 to 0 at a cost E.

There is no possibility to pass from state 0 to m since there would be no sense that a rig owner out of the activity enter in it and maintain the rig idle. It would be more logic to wait for a value that could justify an effective entry without payment of conservation costs in this interval.

In the boundary conditions the managerial actions are incorporated to the model. Using relationships from four of the five mentioned boundary conditions and recalling that in a optimum stoppage problem with binary decision to stop or to continue, there is a boundary-free region (free diffusion of Geometric Brownian Motion) in what the value of first derivatives of the alternatives are equal, we have:

Each state change corresponds to an option exercise. A compound option set is formed and the solution implies in the simultaneous pricing of all options.

We have eight equations with eight positive unknowns: the boundaries P_L, P_M, P_R, P_H and the coefficients A_1, B_2, D_1 and D_2. They can be solved in two blocks. First one considering interaction between temporary stopping and reactivation that generates four equations to four unknowns (P_R, P_M, D_1, B_3 where $B_3 = B_2 - D_2$).

$$- D_1 . P_R^{\beta 1} + (B_3 . P_R^{\beta 2}) + (P_R / \delta) - (C - M)/r - R = 0 \qquad (12)$$

$$- \beta_1 . D_1 . P_R^{\beta 1-1} + (\beta_2 . B_3 . P_R^{\beta 2-1}) + (1 / \delta) = 0 \qquad (13)$$

$$- D_1 . P_M^{\beta 1} + (B_3 . P_M^{\beta 2}) + (P_M / \delta) - (C - M)/r + EM = 0 \qquad (14)$$

$$- \beta_1 . D_1 . P_M^{\beta 1-1} + (\beta_2 . B_3 . P_M^{\beta 2-1}) + (1 / \delta) = 0 \qquad (15)$$

As following, considering conditions of abandonment and entry (or reentry) and with previous unknowns now determined, P_L, P_H, A_1 and D_2 are generated.

$$- A_1 . P_H^{\beta 1} + (B_2 . P_H^{\beta 2}) + (P_H / \delta) - (C / r) - I = 0 \qquad (16)$$

$$- \beta_1 . A_1 . P_H^{\beta 1-1} + (\beta_2 . B_2 . P_H^{\beta 2-1}) + (1 / \delta) = 0 \qquad (17)$$

$$(D_1 - A_1) P_L^{\beta 1} + (D_2 . P_L^{\beta 2}) - M/r + E = 0 \qquad (18)$$

$$\beta_1 . (D_1 - A_1) . P_L^{\beta 1-1} + (\beta_2 . D_2 . P_L^{\beta 2-1}) = 0 \qquad (19)$$

4 – Case Study

For the present study a jack-up platform (PA) has been considered, similar to one MLT 116C (Marathon Le Torneau, cantilever) with top drive and capacity for a water depth of around 100 meters. Certainly the costs utilized in the study are not relative to a specific drilling rig or to a given business condition. However, they correspond to average values representatives for the operation of a common rig, in the patterns of chose unit and under market working conditions.

A basic condition was defined with following parameters:

I = 0, EM = 1.2, E = - 30, R = 0.8 (in million of dollars); C = 8.3, M = 1.0 (in millions of dollars per year); $\sigma = 25$, $\delta = 4$, r = 7 (in % per year).

To solve the hysteresis model proposed by Dixit & Pindyck and adapted in this study of rigs, mathematical optimization software Maple was utilized. It solves non-linear equation systems, differential equations and numerical integration problems. The Successive Approximation method was employed.

In the first trials to solve both sets of 4 equations, each one with 4 unknowns, it occurred problems of non-convergence and it was obtained solutions without economic sense. Initial solution suggestion was rendered difficult by the quantity of parameters, some of which had not intuitive pertinence region. It was observed that coefficients D_1 and B_3 in the first block of equations present linear behavior in the non-linear equations, thus it was possible to place them function of boundaries P_R and P_M. System was then reduced to two non-linear equations, making possible the drawing of graphics to visualize the roots significant for the problem (points in which is null the equation value).

The same procedure of variable substitution by equation elimination was performed for the second set of equations, since coefficients A_1 and D_2 also have linear behavior and can be determined function of P_H and P_L. This makes possible graphic drawing that facilitates very much the determination of root occurrence intervals and the numerical process for equation solving.

Then, coefficients will now be determined by:

$$D_1 = (\beta_2 . B_3 . P_R^{\beta 2 - 1} . \delta + 1) / (\beta_1 . P_R^{\beta 1 - 1} . \delta) \quad (20)$$

$$B_3 = (-P_M^{\beta 1 - 1} + P_R^{\beta 1 - 1}) / (\beta_2 . \delta . (P_M^{\beta 1 - 1} . P_R^{\beta 2 - 1} - P_M^{\beta 2 - 1} . P_R^{\beta 1 - 1})) \quad (21)$$

$$A_1 = - (- P_L^{\beta 1} . r . D_1 - D_2 . P_L^{\beta 2} . r + M - E . r) / (P_L^{\beta 1} . r) \quad (22)$$

$$D_2 = (- P_L^{\beta 1}. r. D_1. \beta_1 . P_H^{\beta 1 - 1} \delta + P_L^{\beta 1} . r . \beta_2 . P_H^{\beta 2 - 1} . \delta . B_3 + P_L^{\beta 1} . r + M . \beta_1 . P_H^{\beta 1 - 1} . \delta \; E . r . \beta_1 . P_H^{\beta 1 - 1}. \delta) / (\delta . r . (- P_L^{\beta 1} . \beta_2 . P_H^{\beta 2 - 1} + P_L^{\beta 2} . \beta_1 . P_H^{\beta 1 - 1})) \quad (23)$$

And the final equations, after a great deal of algebraic work and transformations are as follows:

$$P_R^{(2 . \beta 1 - 2 + \beta 2)} . r . \beta_2 - P_R^{(2 . \beta 1 - 1)} . r . \beta_2 . P_M^{\beta 2 - 1} + P_R^{(\beta 1 + \beta 2 - 1)} . r . \beta_1 . P_M^{\beta 1 - 1} - P_R^{(2 . \beta 1 - 2 + \beta 2)} . r . \beta_1 - P_R^{(\beta 1 + \beta 2 - 1)} . r . \beta_1 . \beta_2 . P_M^{\beta 1 - 1} + P_R^{(2 . \beta 1 - 1)} . r . \beta_1 . \beta_2 . P_M^{\beta 2 - 1} + P_R^{(\beta 1 - 2 + \beta 2)} . \delta . C . \beta_1 . \beta_2 . P_M^{\beta 1 - 1} - P_R^{(2 . \beta 1 - 2)} . \delta . C . \beta_1 . \beta_2 . P_M^{\beta 2 - 1} - P_R^{(\beta 1 - 2 + \beta 2)} .$$

$$\delta . M . \beta_1 . \beta_2 . P_M^{\beta 1 - 1} + P_R^{(2 . \beta 1 - 2)} . \delta . M . \beta_1 . \beta_2 . P_M^{\beta 2 - 1} + P_R^{(\beta 1 - 2 + \beta 2)} . R . \delta . r . \beta_1 . \beta_2 . P_M^{\beta 1 - 1} - P_R^{(2 . \beta 1 - 2)} . R . \delta . r . \beta_1 . \beta_2 . P_M^{\beta 2 - 1} = 0 \quad (24)$$

$$P_R^{(\beta 1 - 2 + \beta 2)} . P_M^{\beta 1} . r . \beta_2 - P_R^{\beta 1 - 1} . P_M^{(\beta 1 + \beta 2 - 1)} . r . \beta_2 + P_M^{(\beta 1 + \beta 2 - 1)} . r . \beta_1 . P_R^{\beta 1 - 1} - P_R^{(2 . \beta 1 - 2)} . P_M^{\beta 2} . r . \beta_1 - P_R^{(\beta 1 - 2 + \beta 2)} . P_M^{\beta 1} . r . \beta_1 . \beta_2 + P_R^{(2 . \beta 1 - 2)} . P_M^{\beta 2} . r . \beta_1 . \beta_2 + P_R^{(\beta 1 - 2 + \beta 2)} . \delta . C . \beta_1 . \beta_2 . P_M^{\beta 1 - 1} - P_R^{(2 . \beta 1 - 2)} . \delta . C . \beta_1 . \beta_2 . P_M^{\beta 2 - 1} - P_R^{(\beta 1 - 2 + \beta 2)} . \delta . M . \beta_1 . \beta_2 . P_M^{\beta 1 - 1} + P_R^{(2 . \beta 1 - 2)} . \delta . M . \beta_1 . \beta_2 . P_M^{\beta 2 - 1} - P_R^{(\beta 1 - 2 + \beta 2)} . EM . \delta . r . \beta_1 . \beta_2 . P_M^{\beta 1 - 1} + P_R^{(2 . \beta 1 - 2)} . EM . \delta . r . \beta_1 . \beta_2 . P_M^{\beta 2 - 1} = 0 \quad (25)$$

$$- P_L^{(2 . \beta 1 + \beta 2 - 1)} . r . D_1 . \beta_1 . P_H^{\beta 1 - 1} . \delta . \beta_2 + P_L^{(2 . \beta 1 + \beta 2 - 1)} . r . \beta_2^2 . P_H^{\beta 2 - 1} . \delta . B_3 + P_L^{(2 . \beta 1 + \beta 2 - 1)} . r . \beta_2 + P_L^{(2 . \beta 1 + \beta 2 - 1)} . r . \beta_1^2 . P_H^{\beta 1 - 1} . D_1 . \delta - P_L^{(2 . \beta 1 + \beta 2 - 1)} . r . \beta_1 . \beta_2 . P_H^{\beta 2 - 1} . \delta . B_3 - P_L^{(2 . \beta 1 + \beta 2 - 1)} . r . \beta_1 - M . \beta_1 . \delta . \beta_2 . P_L^{(2 . \beta 1 - 1)} . P_H^{\beta 2 - 1} + P_L^{(\beta 1 + \beta 2 - 1)} . M . \beta_1 . P_H^{\beta 1 - 1} . \delta . \beta_2 + E . r. \beta_1 . \delta . \beta_2 . P_L^{(2 . \beta 1 - 1)} . P_H^{\beta 2 - 1} - P_L^{(\beta 1 + \beta 2 - 1)} . E . r . \beta_1 . P_H^{\beta 1 - 1} . \delta . \beta_2 = 0 \quad (26)$$

$$P_L^{(2 . \beta 1)} . P_H^{\beta 1} . r - \beta_2 . P_H^{(\beta 2 - 1)} . P_L^{(2 . \beta 1)} . I . r . \delta + P_L^{(\beta 1 + \beta 2)} . \beta_1 . P_H^{(\beta 1 - 1)} . I . r . \delta + P_L^{(\beta 1 + \beta 2)} . \beta_1 . P_H^{(\beta 1 - 1)} . \delta . C - P_L^{(\beta 1 + \beta 2)} . \beta_1 . P_H^{\beta 1} . r - P_L^{\beta 1} . P_H^{(\beta 1 + \beta 2 - 1)} . \beta_1 . M . \delta + P_L^{\beta 1} . P_H^{(\beta 1 + \beta 2 - 1)} . \beta_1 . E . r . \delta + P_H^{(\beta 1 + \beta 2 - 1)} . \beta_1 . P_L^{(2 . \beta 1)} . r . D_1 . \delta - P_L^{(\beta 1 + \beta 2)} . \beta_1 . P_H^{(\beta 1 + \beta 2 - 1)} . r . \delta . B_3 - P_L^{\beta 1} . P_H^{(\beta 1 + \beta 2 - 1)} . \beta_2 . E . r . \delta - \beta_2 . P_H^{(\beta 2 - 1)} . P_L^{(2 . \beta 1)} . \delta . C + P_L^{\beta 1} . P_H^{(\beta 1 + \beta 2 - 1)} . \beta_2 . M . \delta + r . P_L^{(2 . \beta 1)} . P_H^{\beta 2} - P_H^{(\beta 1 + \beta 2 - 1)} . \beta_2 . P_L^{(2 . \beta 1)} . r . D_1 . \delta + \beta_2 . P_H^{\beta 2} . P_L^{(2 . \beta 1)} . r + P_L^{(\beta 1 + \beta 2)} . \beta_2 . P_H^{(\beta 1 + \beta 2 - 1)} . \delta . B_3 . R = 0. \quad (27)$$

For the basic condition the following values were obtained:

$P_H = 23.02$, $P_R = 9.17$, $P_M = 5.69$, $P_L = 5.66$ (in million of dollars per year);

$V_0 (P_H) = 373.20$, $V_0 (P_L) = 43.43$, $V_m (P_R) = 134.48$, $V_m (P_M) = 74.79$, $V_1 (P_H) = 463.20$, $V_1 (P_R) = 135.28$, $V_1 (P_M) = 73.59$, $V_1 (P_L) = 73.43$ (in million of dollars);

$\beta_1 = 1.5168$, $\beta_2 = -1.4168$, $A_1 = 3.2061$, $B_2 = 650.8748$, $B_3 = 360.728$, $D_1 = 4.7825$, $D_2 = 290.1468$.

The boundary values or triggers are best understood if converted to unit of dollars per day, in which freight charges are usually defined. Thus, we have: $P_H = 63070$, $P_R = 25120$, $P_M = 15590$, $P_L = 15510$.

This implies that if daily rate of jack-up would reach US$ 63070, it was interesting to enter in business or to expand by acquisition of a new unit. For daily rates departing from US$ 25120 it would be economic to reactivate a temporarily suspended unit. From this point to US$ 15590 per day, current position would be maintained (activity or temporary suspension) and when reached this limit it would be best to interrupt operation, but keeping asset ownership. For rates inferior to US$ 15510 per day the indication would be the exit from business.

As daily rate for this type of rig is actually US$ 30000, it is interesting to keep the asset and the operation. It had been established a daily operating cost for the rig of US$

22800 and the obtained values show coherence. However, it is observed that for values used in the basic condition, the temporary suspension option is very restricted since only US$ 80 separates it from a complete exit (approximately 0,5%). Thus, with small variations in initial data for costs and rates, this range may increase or even disappear, pointing to a condition of entrance or exit of business without intermediate steps. As follows, these limits are indicated in the sensitivity analysis for all variables.

The comparison of obtained results for option values V_0, V_1 and V_m at the boundary points also present coherence with equations 12 to 15. The opportunity values are situated on high levels, being that $V_1(P_H)$ reaches almost half billion dollars, between operation portion (measured by NPV) and of available options. Inside the interval $[P_L, P_H]$ the difference between V_1 and V_0 corresponds to incremental value for activation/deactivation; in the interval $[P_M, P_R]$ the difference between V_1 and V_m corresponds to incremental value for suspension/reactivation.

After the solution for proposed basic condition, sensitivity analyses were performed with all parameters, changing each one at time, observing its influence on boundary values and attitudes derived from that. The Figures 1.a to 1.i show obtained conditions.

5 – Conclusion

It is observed that for investment or reentry the more significant variables are: acquisition cost, operating cost, volatility and discount rates (net and risk-free) and, at a lower level, the abandonment cost.

For reactivation and temporary stoppage, the operational and maintenance costs are the main influences. With a smaller impact, the lump-sum costs for suspension and reactivation and the volatility are also influences.

For abandonment the more sensible parameters are the exit cost (residual value) and operational cost. Acquisition cost, volatility and discount rates have less influence.

The strong link between decisions to enter and to exit the business is once again configured.

It should be enhanced that changes in one parameter are, in general, followed by changes in others, resulting in complex final effects. This may render impracticable the conditions of temporary suspension or else may create them where do not exist; or can increase or reduce hysteresis intervals, contributing or not for the inertia on attitudes. It is more recommendable the support from Scenario Techniques, helping the evaluation together with the Real Options. It is essential the availability of up-to-date and reliable cost data, on condition of realization of studies far from reality.

Moreover, it should be enhanced that calculated values for P_H were always high, showing that very attractive conditions are required to justify investments of such magnitude; but the option of partnership for acquisition of a rig can be interesting, reducing the risk for each partner, mainly if related to greater exploitation projects involving the companies.

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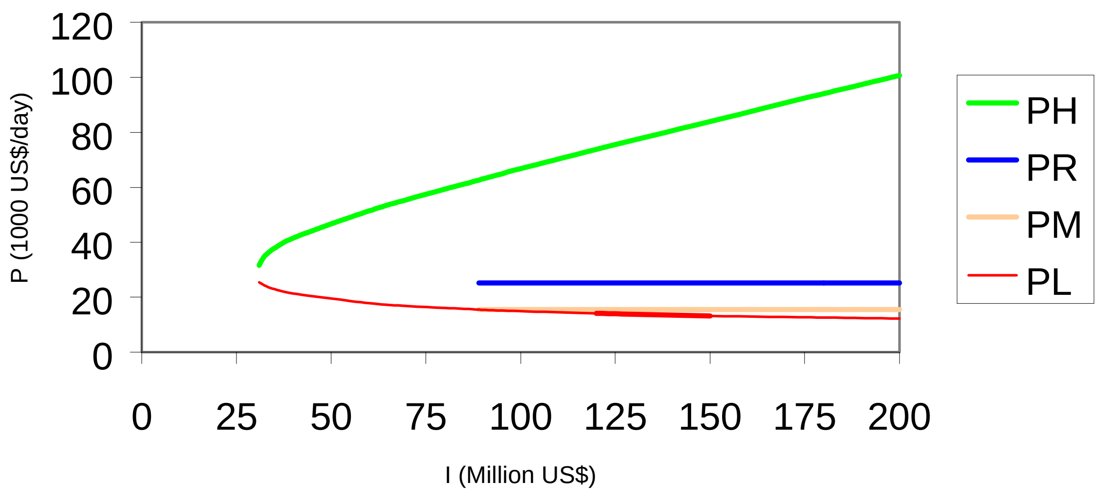

Figure 1.a

Critical thresholds as functions of Acquisition Cost (I)

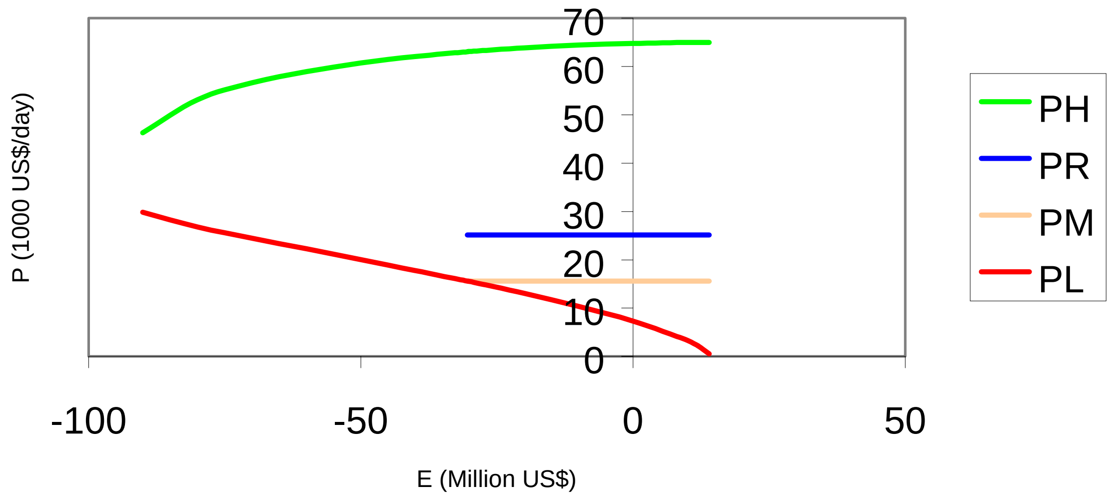

Figure 1.b

Critical thresholds as functions of Abandon Cost (E)

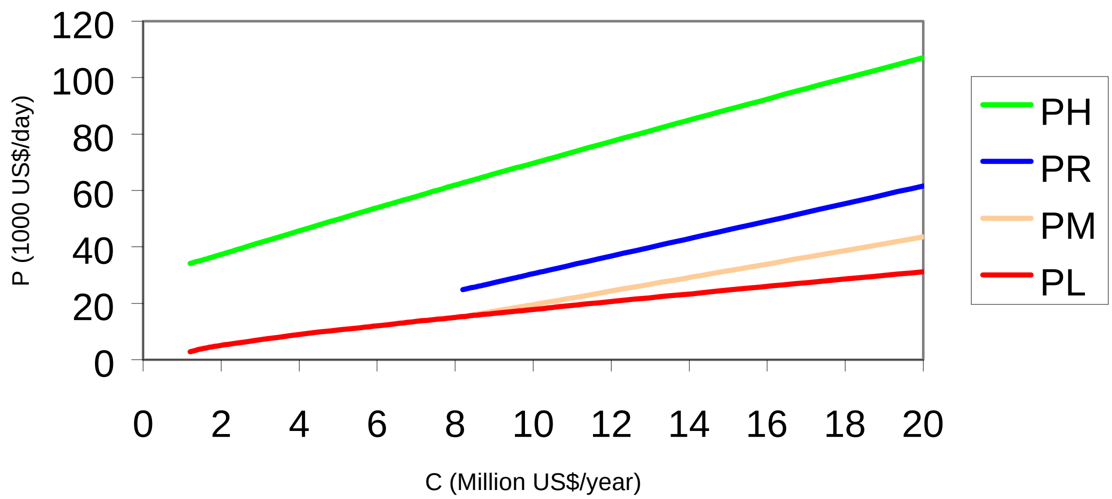

Figure 1.c

Critical thresholds as functions of Operational Cost (C)

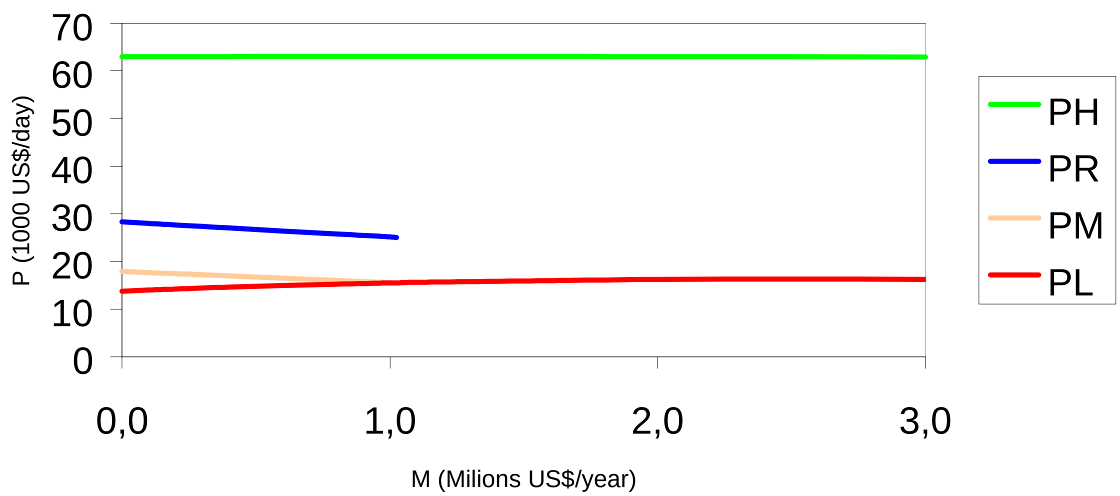

Figure 1.d

Critical thresholds as functions of Maintenance Cost (M)

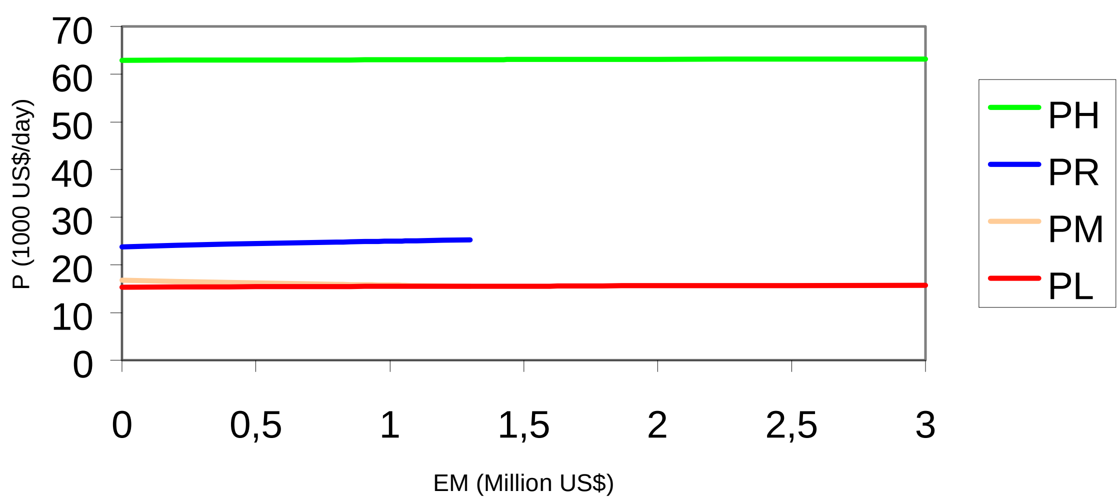

Figure 1.e

Critical thresholds as functions of Temporary Suspension Cost (EM)

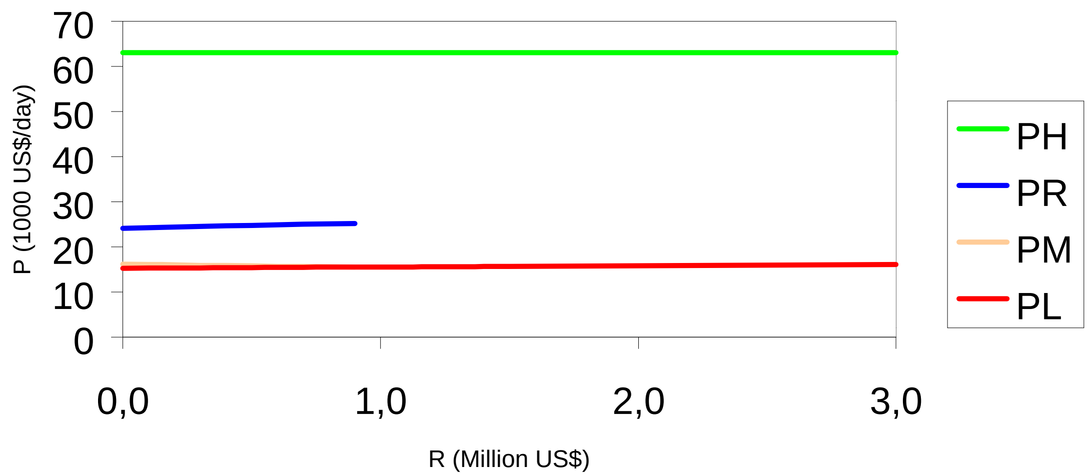

Figure 1.f

Critical thresholds as functions of Reactivation Cost (R)

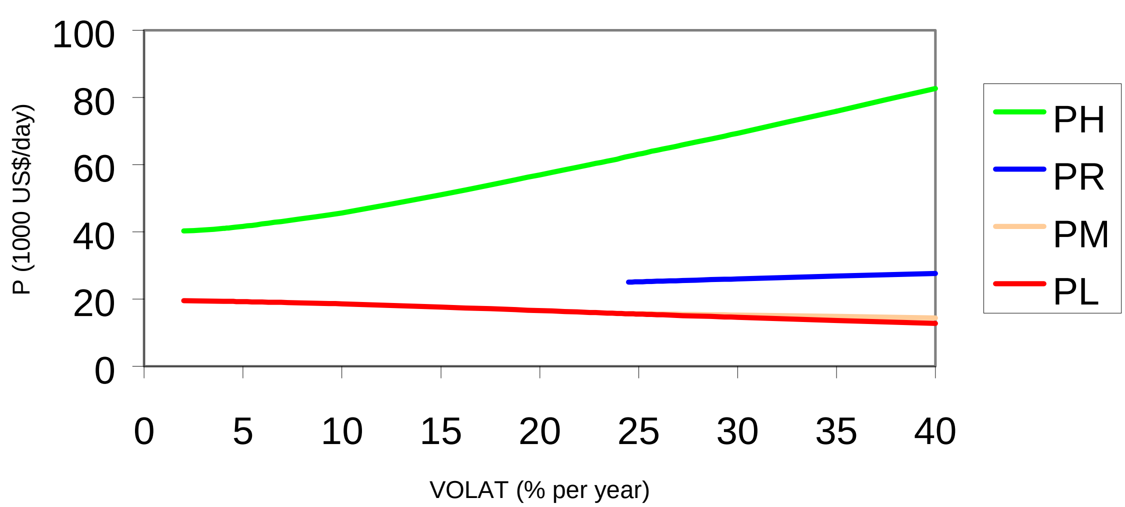

Figure 1.g

Critical thresholds as functions of Volatility (σ)

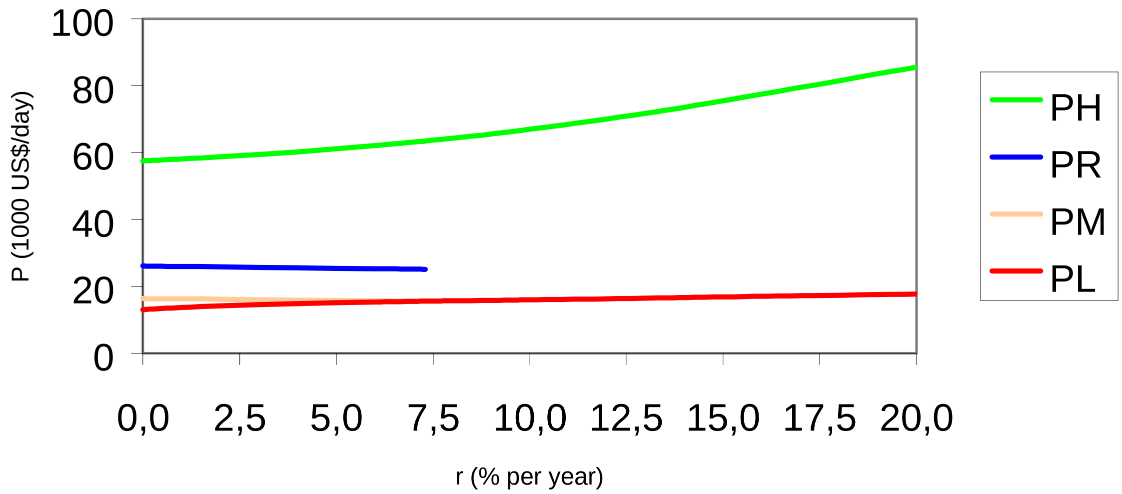

Figure 1.h

Critical thresholds as functions of Risk-free discount rate (r)

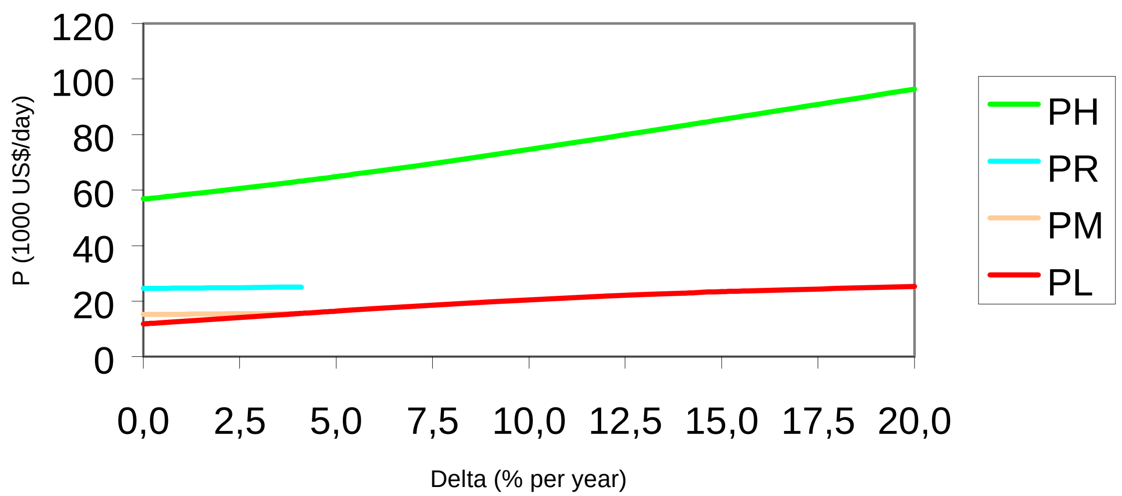

Figure 1.i

Critical thresholds as functions of Convenience rate (δ)