PDVSA: An implementation story of risk-based asset management.

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1 Summary & Introduction

Petroleos de Venezuela is a very large, integrated and government-owned oil, gas and petrochemicals company. From 1995 it embarked on a series of 'bottom-up' Operational Reliability initiatives in its refineries and upstream business – achieving increasing success and significant attitude changes. More recently this has been complemented by a 'top-down' adoption of an Integrated Asset Management model, involving substantial management re-training and the implementation of new organisation structures, performance measures and risk-based decision processes.

Having tried many of the modern reliability and maintenance optimisation methods, each with limited success, PDVSA has evolved (with the help of The Woodhouse Partnership Ltd) a combinational approach including RCM, RBI, TPM, RCA and quantitative cost/risk optimisation tools. A comprehensive criticality analysis technique targets the performance-, cost-, environmental- and safety-important areas (processes, systems, equipment), where the Operational Reliability toolbox is applied to the full, quantitative level of detail. The volume areas of fairly high criticality are handled by a rule-based derivatives, such as RCM/RBI, and template-driven strategies are used for the clearly low-criticality processes/equipment. This technical set of procedures is complemented by a big focus on the human factors – motivation, multi-disciplined team-working, continuous improvement and communications/awareness strategies. The results have been spectacular, particularly for a government-owned company with significant institutional, political and commercial constraints.

Over US$230 Million per year of net benefits have been attributed to the programme so far – and this is reckoned to be just the beginning. This paper describes the journey, which is still on-going, the combinations of tools/techniques employed, and some of the lessons learned along the way.

1.1 Who's who

Petroleos de Venezuela SA (PDVSA) is a state-owned integrated Oil & Gas company that is rated as second largest in the world (by Petroleum Intelligence Weekly), and provides 78 % of Venezuela's export revenues. It ranks third in refining capacity, and fourth in production capacity world-wide. According to Fortune Magazine, it is the tenth most profitable corporation in the world. PDVSA has proven reserves of 74 billion barrels of oil and 145 tera cubic feet of gas. It is estimated that an additional 40 billion barrels are yet to be discovered.

The upstream division of the company is split into 24 'Exploitation Units', set offshore (Lake Maracaibo), in coastal swamps, savannas, rain forests and near desert environments. Downstream, it owns and operates three refineries in the country, including Centro Refinación Paraguana (CRP - the largest oil refinery in the world), and a chemicals plant. It has significant holdings in other production and refining businesses (such as Veba Oil in Germany) and Citgo, one of the largest retail fuel distributors in the United States.

The Woodhouse Partnership Ltd (TWPL) is a small (45-strong) team of grey-haired field-experienced specialists in Asset Management and Operational Reliability. It is based in the UK but with operations in Africa, South America, France and Australasia, and clients in 25 countries – approximately 40% in the petrochemical sector with the balance in utilities, manufacturing, mining and transport industries. TWPL has been providing training and facilitation support to PDVSA since 1996.

2 Where it all started

Back in 1995, the Cardon Refinery was seeking a major performance improvement. Reliability, capacity and efficiency problems were dragging the plant down on international benchmarks. A major upgrade was in progress and a 'Transformation Project' was conceived to raise the operational reliability of the existing infrastructure. RCM was seen as a potential contributor to this process and The Woodhouse Partnership Ltd (TWPL) was asked to perform a baseline audit and then RCM training/facilitation. It was soon apparent that many of the problems were not simply maintenance-treatable but needed basic elimination through root cause analysis and design or behaviour changes. A fixed mindset maintenance, or inspection strategy review, such as that usually promoted by RCM-, RBI- or other 'single solution' vendors, held the risk of being yet another 'temporary enthusiasm'. What was clearly needed was a combinational approach – something that could be adapted to local culture, flexible in scope and depth of application, and targeted to the important issues. And it had to build self-reliance; local competence and confidence to ensure ongoing continuous improvement (rather than rely on expensive external consultancy support). Technology transfer and empowerment were therefore part of the underlying objectives.

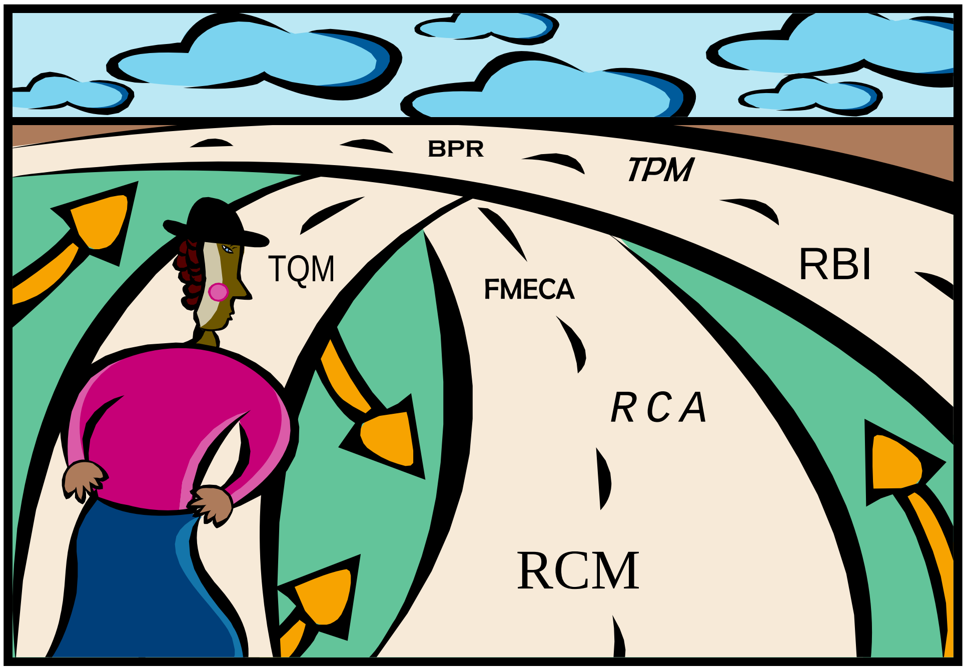

Figure 1. The confusing mix of 'best practice' methodologies

So the initiative was broadened to the full TWPL Operational Reliability model, and a multi-pronged training, investigation and reliability improvement programme was launched. Elements of RCA, RCM, RBI and Cost/Risk Optimisation (CRO) were applied according to the problem criticality and characteristics. Around 300 persons were trained in these methods and the message was – "*get the basics right, and apply sophisticated methods only where clearly necessary*". This approach had rapid impact – pump failures across the refinery, for example, moved from a Mean Time Between Failures of 6 months to an average of 24 months within the first year. Spares requirements were reviewed, maintenance and inspection intervals evaluated and the large number of minor projects screened for simple cost/benefit and risk impact. The annual budget preparations, with around 300 component projects and proposals, were screened, risk evaluated and cost/benefit ranked in record time, with significant improvements in clarity and credibility.

The enthusiasm of operators, technicians and engineers was very encouraging, and the whole refinery management team dedicated time together to understand the Operational Reliability concepts and toolkit. With accelerating successes, therefore, the organisation structure was changed to support the multi-disciplined Asset Management view of performance improvement. Business Units were established with cross-functional expertise, a suite of 'best practice' methods and a common criticality prioritisation approach to ensure consistent value-for-money criteria were applied.

But then, in 1997, the refinery was merged with its neighbour, Amuay, as part of the integration programme of the four PDVSA subsidiaries. The resulting management changes and culture clash effectively stopped all Operational Reliability progress, disbanded the newly-formed business units (by moving back to a function-based organisation for administrational/budgeting convenience) and created a very disillusioned workforce – all within a 6 month period. The erstwhile 'champions' are now spread into other parts of PDVSA, or have left the company altogether. The Cardon experience showed what could be achieved, and then showed how *not* to manage significant organisational change.

3 Meanwhile, upstream…

News of the positive Cardon experiences had been spreading upstream to the Exploration and Production Occidente division (Lake Maracaibo). Led by the maintenance department, a corresponding Interactive Assessment (a baseline audit plus assessment of the potential 'rate of improvement' in various areas) in early 1997 identified the considerable scope for Operational Reliability improvement – even a 1% availability/production gain would yield between US$56 and 67 Million/year of extra revenues. A target of 3-5% improvement was suggested as achievable (despite considerable local scepticism) from the current platform of 85-90% availability, so a series of pilot studies were performed. These found immediate real opportunities for change, with significant cost and performance benefits. Once again, the *combination* of Root Cause Analysis, RCM rules and quantified Cost/Risk/Performance Optimisation methods yielded much more than any single methodology would have done. It provided a 'toolbox' approach with adequate focus on true technology transfer (creating local 'ownership' of the methods, and in-house facilitators). The toolbox consisted of a criticality-based application of the appropriate depth of sophistication, and multi-disciplined review and agreement of the best way forward (see Figure 2).

The pilot studies were deemed a success, and a wider implementation of Operational Reliability methods was initiated. This was timely, as a company-wide push towards "World Class Maintenance" had been started by the central Maintenance Services department. As would rapidly become clear, however, a focus on functional excellence (better *maintenance*) is an uphill struggle: unless the beneficiary of maintenance (i.e. production) is closely involved, it is almost impossible to achieve sustained improvement activities. RCA and RCM activities provided the vital catalyst for this collaboration as, historically, the divide between maintenance and production had been strong (separate budgets, performance monitoring etc).

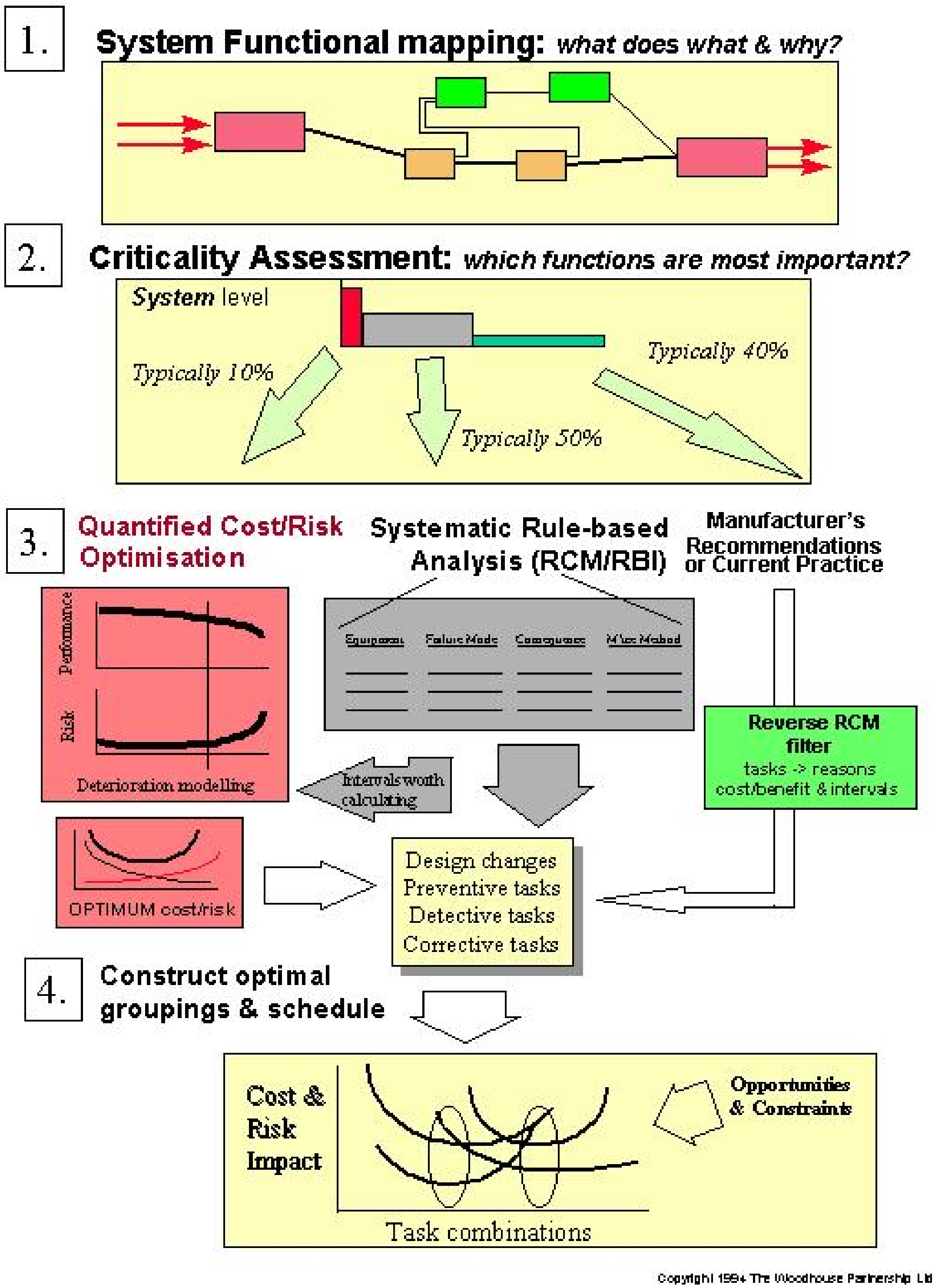

Figure 2. A multi-threaded approach to risk and maintenance strategies

3.1 The Investment

3.1.1 Training

The impressive CIED training division of PDVSA was called in to provide logistical support, and the following education programme was rolled out over the period 1997-2000:

Topic	**No. of persons trained**
Operational Reliability (Concepts introduction level only)	391
Root Cause Analysis	154
Reliability Centred Maintenance	468
Risk Based Inspection	108
Cost/Risk Optimisation	112
System Reliability Engineering	70
Facilitator Skills	49
High performance/process management	59
Shutdown management	12
Operational Reliability integration	24
Total trainees	**1,447**

Training courses varied from 1-day workshop-style events to 10-day intensive coaching programmes. Participants were drawn from the full range of functional specialisms: 374 were from production operations, 42 from the gas compression plants, 50 from electrical utilities, 34 from marine operations, 47 from drilling, 55 from construction, 67 from planning, 245 from maintenance/inspection, 17 from logistics support, 18 from project engineering and 14 specialists in Operational Reliability.

3.1.2 Teamworking, facilitation & tools

Starting with a team of 6 facilitators, the Operational Reliability group was lead by a Maintenance Superintendent, Luis Fernandez . This group supported a series of multi-disciplinary working teams, meeting on average once per week. As the results became apparent, the volume demand for similar studies grew and the activity level peaked with 27 facilitators supporting study teams in 1999-2000. As local competency and experience grew, so the dependence on external experts dropped away, down to a level of quarterly quality control weeks, at which teams presented their work and queries to one of the TWPL advisors for comments and directional guidance. Having reviewed the large majority of critical systems and maintenance strategies, this work programme has now stabilised to a level of 'Continuous Improvement', with around 6 dedicated facilitators and 'top up' training for new faces and new topics (such as Asset Management and Life Cycle Costing). The experiences are also being templated and shared across 'knowledge networks' with other areas of the company.

It should be noted that a cultural strength of the Venezuelan engineers is approach to collaboration in teams, and the PDVSA endorsement of 'Natural Working Teams' harnesses this willingness to share and work together. The downside of this attribute, on the other hand, is the reluctance to take decisions – relying instead on referral upwards, procrastination or committee-based strategies. The Operational Reliability implementation took this into account, introducing APT software tools to provide hard numbers and risk-evaluated options, both to exploit the multi-disciplined 'tacit knowledge' in a structured way, and to encourage greater decision-making confidence. This proved a key to the ongoing credibility of the initiative: the teams could 'prove' the value of the proposed changes and provide an audit trail of assumptions and "what if?" comparisons with existing or alternative strategies.

3.2 The results so far

In this sector the Operational Reliability initiative has achieved spectacular and sustained successes. The following is a small sample of the types of activity that occurred in 2001, and the measured or potential impact discovered.

Exploitation Unit	**Example studies**	**Impact (potential or realised benefits)***
Lagomar	Optimisation of scope for major overhaul in flowstations	$500k/year realised
	RBI review of flowstation inspection tasks	$220k/year realised
	Reliability analysis of pipeline risers	$300k/year potential $80k/year realised so far
Lagomedio	Optimisation of production facilities maintenance	$220k/year realised
	RBI review of flowstation inspection tasks	$2 Million/year realised
	Redesign of maintenance plans for production manifolds, separators, tanks and pipelines	$800k/year potential $300k/year realised so far
	Redesign of pump maintenance	$300k/year potential
	Renewal interval for valves	$200k/year realised
	New maintenance strategy for intelligent control valves	$450k/year potential
La Salina	Maintenance optimisation of flowstation TJ21	$120k/year realised
	New technology solutions for motor condition monitoring	$80k/year potential
Tierra Oeste	Risk analysis of 24" effluent pipeline	$3million/year potential
Tia Juana Lago	Maintenance interval for water injection train	$60k/year realised
	Use of predictive maintenance technique (Ultraprobe)	$120k/year potential
	Improve procedure for electric motor repairs	$60k/year potential
	New maintenance strategy for storage and pumping	$ 90k/year potential
	Preventive maintenance intervals for dynamic equipment in water injection	$22/year potential
Tierra Pesado Este	Root Cause Analysis of electric motor failures	$210k/year potential
	Redesign of maintenance plans for steam plant	$620k/year potential
	Redesign of maintenance plans for hoists / cranes	$2.6 Million/yr potential
Lagocinco	Use of venting packer in 16" pipeline risers	$1.6 Million/year potential

	Redesign maintenance strategy for oil & gas pipelines	$2 Million/year potential
	New maintenance strategy for separation system	$150k/year potential
	New maintenance strategy for intelligent control valves	$520k/year potential

** "Potential" benefits are those calculated for the implemented solutions that have a long lead-time, or risk-based impact. "Realised" are those validated by direct measurement. In both cases, the benefits are the* ***net*** *impact of costs (capex & opex), reliability, availability, production rates and efficiency etc.*

The mix of methods that were applied in each case varies, of course, but an analysis of the *principal* methods used for each case reveal the following distribution, along with the interesting difference between *anticipated* potential impact ("visualised") that was the original basis for prioritising studies, and *real* benefits achieved by the studies themselves. This shows how difficult it is to predict the scope for improvement before the disciplined analyses are performed.

	ANALISES			TOTAL IMPACT ($K/year)	
Methodology	PLANNED FOR 2002	COMPLETED (1st 6 months)	IN PROGRESS at July 2002	VISUALISED 2002	ACHIEVED AT jULY 2002
CRITICALITY ANALYSIS	6	1	9	-	-
LOST OPPORTUNITY ANALYSIS	3	-	3	-	-
CROSS-FUNCTIONAL TEAMS BUILD	1	1	3	4865	350
ROOT CAUSE ANALYSIS	16	1	9	13890	1100
STATISTICAL DISTRIBUTION ANALYSIS		1	-	-	-
RELIABILITY CENTRED MAINTENANCE	14	1	12	888	5269
RISK BASED INSPECTION	7	1	2	600	-
COST/RISK OPTIMISATION (APT)	10	8	9	950	15140
OPERATIONAL IMPROVEMENTS	13	1	10	780	1500
NEW TECHNOLOGY APPLICATIONS	11	1	9	1480	176
SYSTEMS RELIABILITY ENGINEERING	4	1	5	1500	457
	85	17	71	24,953	23,992

Figure 3. Summary of 6-months results

4 Migration from maintenance- to production-led

Despite the substantial successes of the Operational Reliability programme, and its progressive spread to other regions of the country, a newly-established "Centres of Excellence" group in the Caracas headquarters realised that the big prizes lay in applying similar concepts to *production* decisions (rather than just equipment and facilities reliability/maintenance). This launched a production derivative of Operational Reliability called "Reliability-Based Production" (PBC).

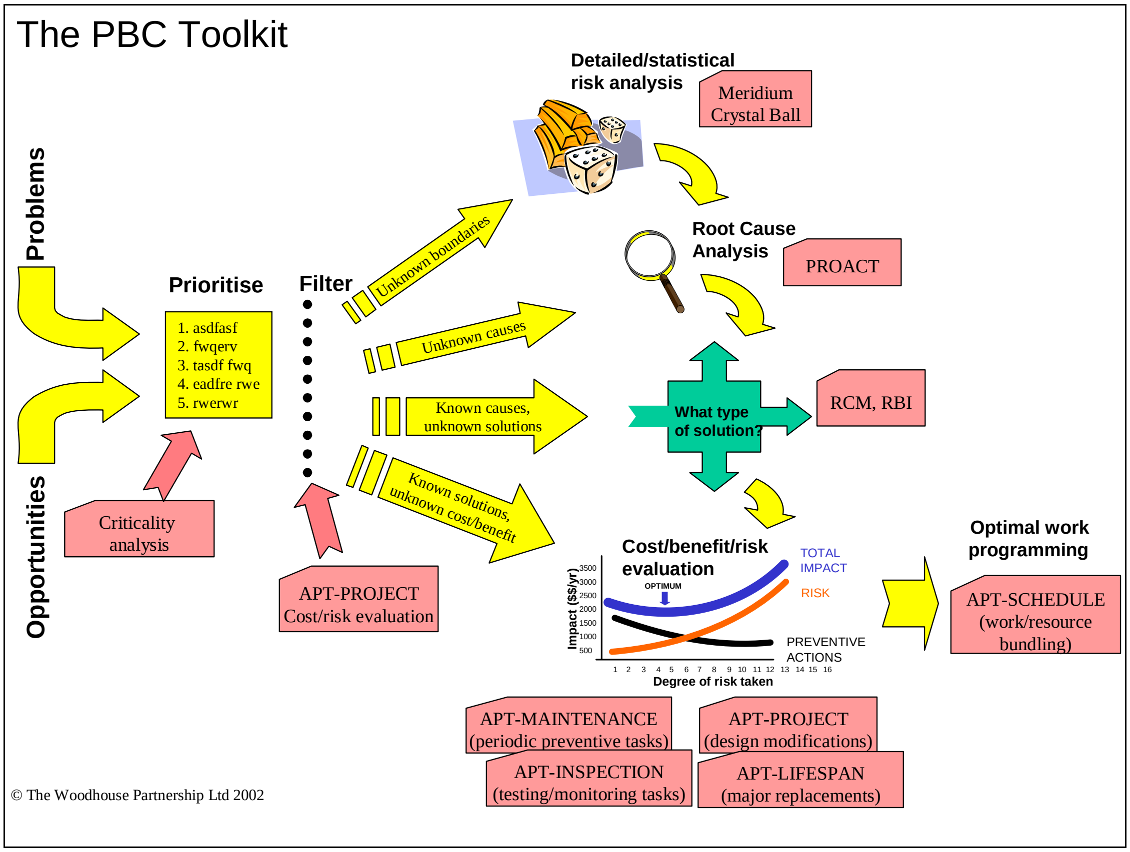

Figure 4. The PBC toolkit

Three of the Operational Reliability lead facilitators were released to help and, jointly with TWPL, a customised 9-week on-the-job training programme was devised. The first three groups have now completed this programme and have already generated some remarkable results. The numbers are certainly even larger than those of the earlier studies – decisions are directly related to production figures and total reserve potential. Drilling studies, reservoir management options, well workovers, tubing replacements, down-hole equipment and monitoring strategies have all proved to be directly amenable to the disciplined, risk-based study methods and deterioration modelling tools. A representative example is shown below:

4.1 Asphaltene plugging of wells in Pirital UE

Current situation: rapid accumulation of asphaltene deposits restrict production rates until the wells are totally blocked (at which point, coiled tubing is used to re-open/clean the well). Current frequencies for this blocking vary from 1-4 times per year for each well.

Analysis process: APT-MAINTENANCE™ software was used to describe both the progressive efficiency loss (through partial plugging) and the distribution of total blockages (including other sources of blockage, such as well workover errors or other, random events). The costs of planned and reactive cleaning were also entered, along with the downtime impact for such events.

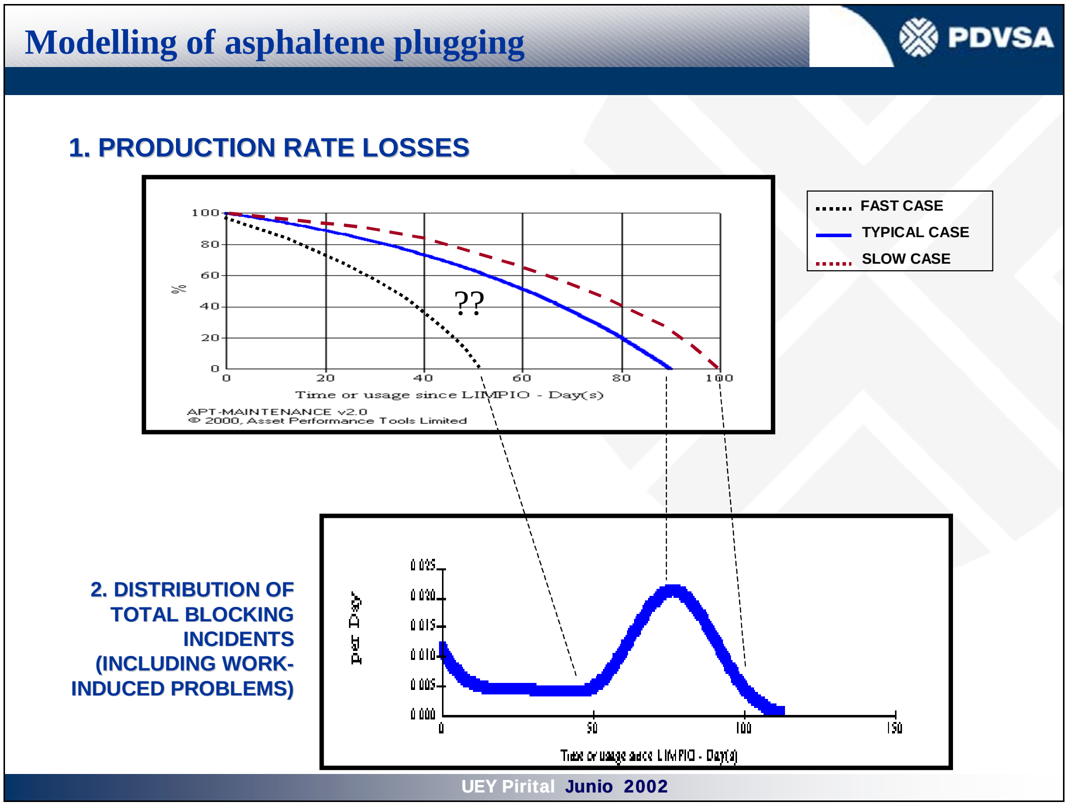

Figure 5. Deterioration modelling and reliability pattern description

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Results (average case): OFM = On-Failure Maintenance (current policy)

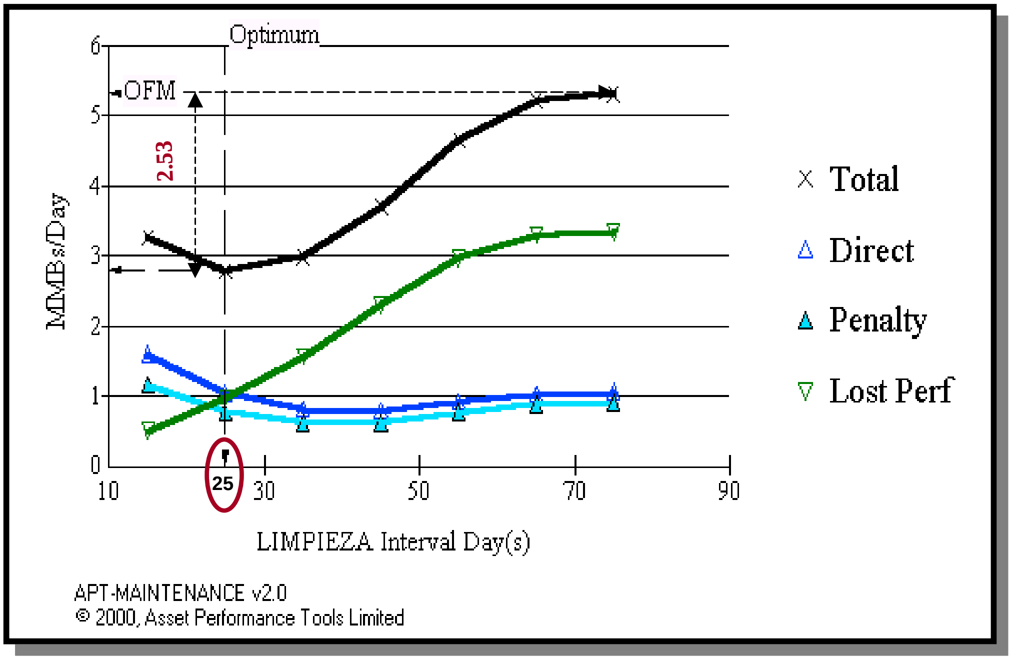

Figure 6. Cost/risk/performance trade-off results, showing that partial efficiency losses are ample to justify planned shutdowns and cleaning costs.

The systematic results of this study, customised for the performance profiles for each of the 11 affected wells, revealed the following optimal cleaning strategies and net benefits (totalling over $5.3 Million/year compared to current policy):

WELL	Optimal Frequency & range (/yr)	% losses at the opt. cleaning pt.	% losses at current avge cleaning	Net Benefit (US$k/year)
SBC 20SL	5 (4-6)	7.12	16.0	211.7
SBC 57L	3 (3-5)	5.45	11.42	266.45
SBC 97 M	6 (5-8)	11.7	10.0	0.0
SBC 115 M	7 (5-11)	16.9	50.76	981.85
SBC 98	3 (2-4)	7.84	14.15	180.31
SBC 100	4 (4-5)	6.52	4.3	0.0
PIC 24	8 (6-10)	20.8	64.43	1620.6
SBC 45 L	2 (2-3)	4.12	12.0	602.25
SBC 104	7 (6-10)	13.3	14.5	3.64
SBC 103	4	6.46	26.86	1394.3
SBC 94	3	5.92	8.0	80.3
			TOTAL	5,341.41

Figure 7. Summary results of well cleaning optimisation

5 The next stage: Integrated Asset Management

The next chapter in the story began two years ago with a parallel initiative started by the Centres of Excellence team – exploration of a total integrated approach to Asset Management, along the lines applied with great success by the North Sea oil and gas companies. This activity, facilitated by Edinburgh Petroleum Services, the Robert Gordon University in Aberdeen (and TWPL), was launched as an education programme for middle and senior managers in the Exploration and Production division. This originally comprised a16-week programme in Scotland for teams of 14 managers at a time. This included the 'hands-on' development of asset management plans for each Exploitation Unit. On the 4th such programme now, the teaching programme has been tuned and, with budget cuts, reduced to 9 weeks of overseas work, supplemented by local (Venezuelan) coaching. The implementation of an 'asset-centred' organisation has begun, using Exploitation Units and Districts as the discrete assets for

The Integrated Asset Management ("GIA") is stated as the new business model for PDVSA Exploration and Production, yet there are some significant barriers to its full implementation. The existing annual cycle of budget authority, the strong vertical separations of budget controls and functional authority, and the resistance to empowered decision-making will provide plenty of challenges. Nevertheless the direction, the vision and evidence of substantial benefits are clear. PDVSA is making substantial investments and achieving some big improvements. It is taking on new ideas, and making familiar techniques work in a sustainable manner. Even the 'knowledge communities' on the corporate intranet are actually used to share best practice and experiences. In short, and despite the current political environment and reputation for Latin American cultural resistance, PDVSA is going to achieve some remarkable advances in the next few years. A joined-up top-down new approach to the business (GIA) and a number of bottom-up initiatives for tools, skills and methods (Operational Reliability, SAP etc.) are at the heart of this transformation.

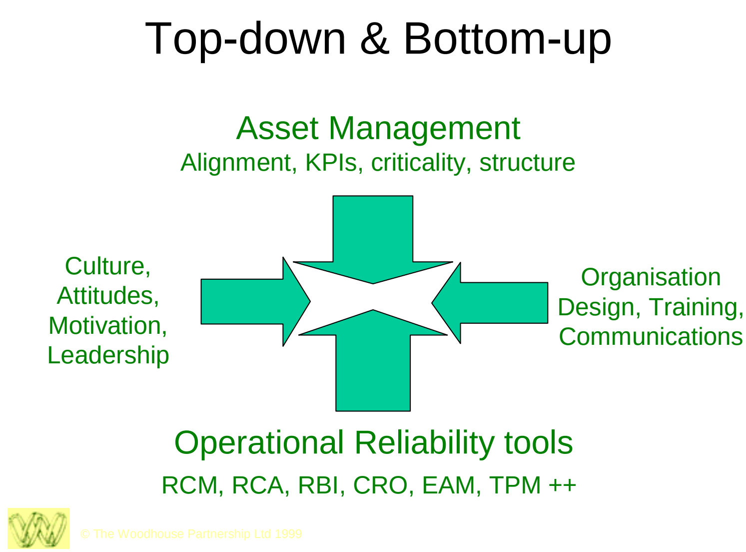

Figure 8. Top-down and bottom-up initiatives in harmony

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