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"RAM + L analysis: A case study in Brazilian refinery"

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ABSTRACT: The main objective of RAM analysis (Reliability, Availability and Maintainability) is assessing equipment or system performance throughout critical equipment improvement in order to achieve an availability target. To carry out RAM analysis it is necessary to define the equipment failure modes which have the highest impact on system availability. The analysis is carried out using historical failure data and repair time and simulation using a reliability diagram model model. Despite widespread applicability of this methodology on large complex systems it is vitally important that logistics issues must to be considered. There are two different approaches, the first one focuses on reliability issues and the second one on logistic. At this time in Brazil there is no methodology which considers these two issues, logistic and reliability in only one Methodology, in order to assess huge logistic system regarding reliability issues of subsystems and equipments into logistic systems. In fact complex systems logistic analysis do not take into account reliability issues and the other way rounds.

The RAM + L analysis methodology takes into account logistic and reliability issues in order to have a more representative result to support improved decisions. The case study consists of a complex system comprising refineries plants (Vacuum and Atmospheric Distillation Plant, Thermal Cracking Plant, Acid Water Plant, Cracking Catalytic Plant, Reforming Catalytic Plant, Fractioning Plant, DEA, Nafta and Diesel Hydrodesulphurization Plant) and Tanks will be carried out to assess advantages, drawbacks and to compare RAM analysis with the results obtained using the RAM + L analysis.

Keywords: RAM Analysis, RAM + L Analysis, logistic, availability

1 INTRODUCTION

The availability analysis of a system is essential to verify the possible enhancements to be carried out on critical sub-systems and equipment in order to maintain the system availability goal. Availability is influenced by reliability and by maintainability, making it essential to carry out an evaluation of failure and repair occurrences in order to identify the most critical equipments with respect availability.

In order to carry out RAM analysis is necessary to specify the system's borders and define scope. This will require an evaluation of sub-systems, equipment and components which failures represent environmental impacts, damages to personal safety and physical damage, loss of production and system halt. The System Configuration will comprise a set of blocks linked in series and in parallel as illustrated in Figure 1, shown below.

The reliability of a system is the probability of a system working without failure for a specified period of time. Another important concept of availability analysis of a system is the maintainability, what means the probability of equipment being repaired in a specific period of time. That

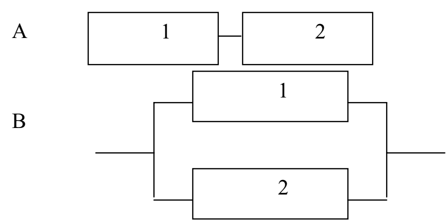

Figure 1. Reliability block diagram.

In case A, reliability is represented as:

$$R(t) = R(t)1 \times R(t)2$$

In case B, reliability will be:

$$R(t) = 1 - ((1-R(t)1) \times (1-R(t)2))$$

will impact the equipment's availability which may be understood as the probability of certain equipment being available for a length of time.

In general, the analysis of a system must take reliability and maintainability into consideration, since these two factors affect the availability of a given system. It is possible to identify critical equipment in terms of maintenance and failure through this analysis, so that managers can take the best decision to optimize availability with the lowest cost.

The principle objectives of a technical system are to ensure the realization of continuous operation process of its components. However, a population of units (aircraft engine components, computer modules, means of transport, etc.) that randomly fail but are completely repairable requires and effective maintenance infrastructure and logistic system, that will be available when required. As result, reliability and effectiveness of technical system, being worked in changeable environment, cannot be analyzed in isolation, without taking into account the numerous links with its logistic support system (Werbinska, 2007).

This case study in a refinery was analyzed with omitting all external factors to the unit, such as steam, cooling water and other influences it was assumed that all external resources are 100% available. Failure and repair data of the unit was used in this stage.

Moreover, System analysis will be carried out taking into account reliability availability, maintainability and a complex logistic assessment which comprises such plants and regards further logistics issues using RAM + L (Reliability, Maintainability, Availability + Logistic) methodology. Such methodology comprise phases like scope definition, System RAM analysis, Logistic assumptions, RAM + L Analysis, critical analysis sensitivity analysis, and conclusion.

Scope phase has main objective to define analysis boundaries in order to focus on defined systems and logistic resource avoiding delays caused for scope changes or increment.

System RAM Analysis is required in order to consider critical systems and their equipment which may take a high influence in whole Complex system availability. In case of not required such analysis is being performed a logistic analysis only.

Logistic assumptions is required in order to model logistic issues like tank levels, flow priorities in process, ships load or other modal capacity, delays and stock levels.

After performed system RAM analysis and to get logistic assumption is possible to comprise all information and model complex system regarding both issues.

After simulation critical analysis are required and usually reliability, availability and utilization will indicate which are the critical systems and logistic resources.

In some case, some situation which may increase system vulnerability was not took into consideration and it's must to considered in model. The stock level, energy supply and facilities unavailability are some examples which may decrease system availability.

After critical and sensitivity analysis the conclusion will summarize critical equipments, logistic resources and further vulnerabilities system as well as improvements actions which must take in place in order to achieve high complex system performance.

2 DATA PROCUREMENT

A huge challenge to Brazilian Oil and Gas Industry is to get good data to perform RAM analysis. In order to ensure the reliable level of such data, maintenance professionals with knowledge of the these systems took part in this stage and a semi-quantitative analysis of failure and repair data is carried out in some cases.

A equipment analysis into the causes of system downtimes requires failure modes were performed and identified along time, it means all equipment failure modes responsible for most of the impacts in respective sub-systems. The failure data equipment is treated statically in order to define the best PFD (probability density function) which bests fit the historical failure data and is necessary to have software's support such analysis (weilbull 7 ++ reliasoft). As instance, is shows an example in Table 1 below a Thermal cracking Furnace failures modes with each PFD and repair time.

Statistical analysis was performed for more than 200 equipment to enable direct simulation (Monte Carlo) to represent operation time in 3 years. The coke formation is the most critical event in refineries plants. Coke formations is considered the most critical failure mode in the RBD modeling (Reliability Block Diagram Block), but is considered a process failure. The Figure 2 below summaries RAM + L methodology.

3 SYSTEM MODELING

To perform the availability results in Monte Carlo simulation, it is necessary to set up a RBD model.

Table 1. Failures and repair data.

TAG	Failure mode	Failure time (years)				Repair time (hours)		
		Variables (PDF)				Variables (PDF)		
F-01 A	Coke formation	Normal		μ	ρ	Normal	μ	ρ
				4,95	2,66		420	60
	Incrustation	Weibull	β	η	γ	Normal	μ	ρ
			0,51	1,05	4,05		420	60
	Others failures	Exponencial Bi p		λ	γ	Normal	μ	ρ
				0,28	3,22		420	60
F-01 B	Coke formation	Normal		μ	ρ	Normal	μ	ρ
				5,23	2,55		420	60
	Others failures	Exponencial Bi p		λ	γ	Normal	μ	ρ
				0,29	4,07		420	60

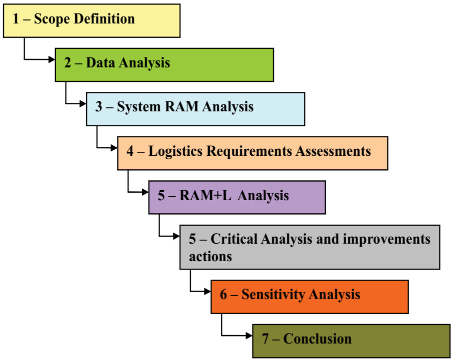

Figure 2. RAM + L methodology.

Although the system is complex it was decided to use RBD (Reliability Diagram Block) methodology. In order to perform Monte Carlo Simulation, it is necessary to be familiar with the production flow data which influence losses in productivity. Consequently, some statements and definitions regarding process limitations.

3.1 *Atmospheric Distillation Plant (U-11)*

Based on general process assumptions, The RDB (Reliability Diagram Block) of the Atmospheric Distillation Plant comprise five blocks in series which represent Feed, Desalter, Heating, Furnace, Atmospheric Distillation and LPG Treatment. This means if one block fails down the whole System will be unavailable.

Each Subsystem represented in the RDB, comprises several equipments with each PDF (probability density function). The assumptions to perform RDB model are:

- It's not being regarded facilities availability and other supply influence in U-10 availability;
- Subsystem unavailability represents system fail downtime;
- The average availability target is 97,0% over 3 years;
- Total Production per day is 1.500 m^3/day.

In Figure 3 below does shown RDB which comprise five main diagram blocks.

Despite having a heavy oil feeding most of time, right equipment project specification and correct maintenance policy along time permit system restore their life in each 5 years, as doing so, System Availability must be high as it will be discussed in item 4. In fact, most of equipments are as good as new mainly the static ones. Most dynamics equipments as pumps have redundancy and it permit high performance even thought equipment reliability is not so high.

3.2 *Atmospheric and Vacuum Distillation Plant (U-10)*

The main objective of Vacuum Distillation plant is to change out heavy oil portion in light oil product. Based in general assumptions, The RDB (Reliability Diagram Block) of Vacuum Distillation Plant comprise five blocks in series which represent Feed, Desalter, Heating, Furnace, Atmospheric Distillation and vacuum Distillation. That means if one of block fail down the whole RDB will be unavailable. Each subsystem represented for RDB comprises several equipments with each PDF based in failures modes. The main assumptions to make up RDB are:

- It's not being regarded facilities availability and other supply influence in U-10 availability;
- The equipment failures modes are based in failure historical data of own Plant from 2000 to 2010;
- Subsystem unavailability represents system fail down;
- The average availability target is 98% in 5 years;
- Total Production per day is 5.600 m^3/day.

In Figure 4 below does shown RDB which comprise three main diagram blocks.

Different to Atmospheric Distillation Plant (U-10), Vacuum Distillation have a light oil feeding most of time and that condition preserve equipment. In addition, right equipment project specification and correct maintenance policy along time permit system restore their life in each 5 years, as doing so, System Availability most be high as it will be discussed in item 4.

3.3 *Thermal Cracking Plant (U-211)*

The main objective of Thermal Cracking is convert heavy feed from Atmospheric Distillation (U-11) into diesel product.

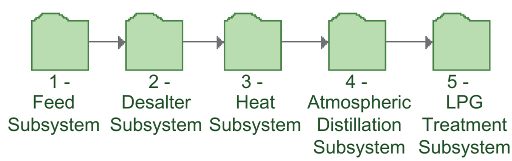

Figure 3. Atmospheric Distillation RDB.
Source: Author, 2010.

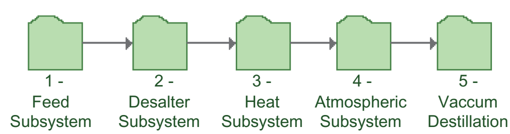

Figure 4. Distillation RDB.
Source: Author, 2010.

Based in general assumptions, The RDB (Reliability Diagram Block) of Thermal Cracking Plant comprises five blocks in series which represent Feed and Preheater, Thermal Cracking, Fractioning, compression and Stabilization. That means if one of block fail down the whole RDB will be unavailable. Each sub system represented for RDB comprises several equipments with their PDFs based in failures modes. The main assumptions to make up RDB are:

- It's not being regarded facilities availability and other supply influence in U-211 availability;
- The equipment failure modes are based in failure historical data of similar Unit Plant from other refinery;
- Subsystem unavailability represents system fail down;
- The availability target is 97,0% in 3 years;
- Total Production per day is 1.500 m³/day.

In Figure 5 below does shown RDB which comprise five e main diagram blocks.

3.4 *Diesel Hydrodesulphurization Plant (U-13)*

The main objective of the Diesel Hydrodesulphurization is to separate out sulphur component from diesel which come from the Atmospheric and Vacuum Distillation (U-10), Atmospheric Distillation (U-11) and Thermal cracking Plant (U-211). Based on the general assumptions, The RDB (Reliability Diagram Block) of the Diesel Hydrodesulphurization Plant comprise eight blocks in series which represent Feed, Reaction, H2 make up, H2 recycle, Diesel Fractioning, Drying Subsystem and Cleaning Water. That means if one of block fails down the whole RDB system will be unavailable. Each sub system represented in RDB comprises eight equipments with their PDF (Probability Density Function) based on the historical failures modes. The main assumptions for this System RDB are:

- It's not being regarded facilities availability and other supply influence in U-13 availability;
- The equipment failure modes are based in failure historical data of similar Plant from other refinery;
- Subsystem unavailability represents system fail down;
- The average availability target is 98% in 3 years;

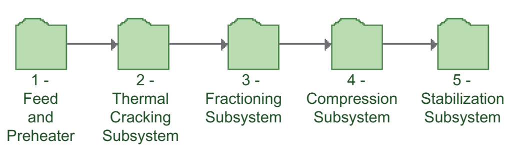

Figure 5. Thermal Cracking Plant RDB.

- Total Production per day is 2500 m³/day.

In Figure 6 below does shown RDB which comprise eight main diagram blocks.

3.5 *Nafta Hydrodesulphurization Plant (U-12)*

The main objective of Nafta Hydrodesulphurization is to separate sulphur component from nafta feed from Atmospheric and Vacuum Distillation (U-10), Atmospheric Distillation (U-11) and Thermal cracking Plant (U-211).

Based in general assumptions, The RDB (Reliability Diagram Block) of Nafta Hydrodesulphurization Plant comprise four blocks in series which represent Feed, Reaction, H2 make up, H2 recycle, Diesel Fractioning, Drying Subsystem and Cleaning Water . That means if any one of block fail down the whole system is down. RDB (Reliability Diagram Block) will be unavailable. Each sub system represented in the RDB comprises eight equipments with their PDF (Probability Density Function) based in failures modes.

- It's not being regarded facilities availability and other supply influence in U-12 availability;
- The equipment failure modes are based in failure historical data of similar Plant from other refinery;
- Subsystem unavailability represents system fail down;
- The average availability target is 98% in 3 years;
- Total Production per day is 2500 m³/day.

In Figure 7 below does shown RDB which comprise eight main diagram blocks.

One of the most of important process condition is that H2 make up compressors (A/B) in Diesel

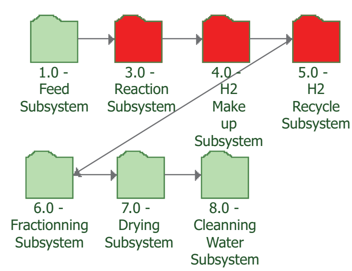

Figure 6. Diesel Hydrodesulphurization RDB.

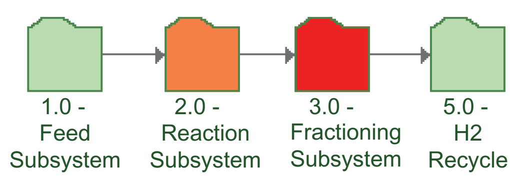

Figure 7. Nafta Hydrodesulphurization RDB.

Hydrodesulphurization (U-13) supply H2 to both plants U-12 and U-13. In doing so, in case of unavailability in H2 make up compressors both Plants will be unavailability.

3.6 *Acid Gas Treatment (DEA—U-23)*

The main objective of Acid Gas Treatment plant is to separate sulphur component from gas produced in Nafta and Diesel Hydrodesulphurization. Based in general assumptions, The RDB (Reliability Diagram Block) of DEA Plant comprises many types of equipment like vase, pumps, heat exchangers and towers in series. That means if one of equipment fail down the whole System will be unavailable. In this case, like other subsystems and systems the pumps are in parallels configuration. It means that is necessary both pumps fail down to shut down DEA Plant. The main assumptions to make up RDB are:

- It's not being regarded facilities availability and other supply influence in U-23 availability;
- The equipment failure modes are based in failure historical data of similar Plant from other refinery;
- Subsystem unavailability represents system fail down;
- The availability target is at least 98% in 3 years;

In Figure 8, DEA RDB subsystem is represented comprising vases, pumps and towers.

3.7 *Acid Water (U-26)*

The main objective of Acid water Treatment plant is to separate out sulphur component from gas produced in Nafta and Diesel Hydrodesulphurization. Based in general assumptions, The RDB (Reliability Diagram Block) of DEA Plant comprises many types of equipment like vase, pumps, heat exchangers and towers in series. That means if one of block fail down the whole RDB will be unavailable. In this case, like other subsystems and systems the pumps are in parallels configuration. It means that is necessary both pumps fail down to shut down DEA Plant. The main assumptions to make up RDB are:

- It's not being regarded facilities availability and other supply influence in U-26 availability;
- The equipment failure modes are based in failure historical data of similar Plant from other refinery;
- Subsystem unavailability represents system fail down;
- The availability target is at least 98% in 3 years;

In Figure 9, Acid water RDB subsystem is represented comprising vases, pumps and towers.

One of the most important assumptions in Acid Water Plant is that in case of unavailability in such Plants, others plants are unavailable as Vacuum and Atmospheric Distillation Plant (U-10), Atmospheric Distillation Plant (U-11), Thermal Cracking Plant (U-211), Nafta and Diesel Desulphurization (U-2312/U-2313) and Catalytic Cracking Plant. Despite high Acid Water availability, there's no significant impact in refinery regarding Acid Water Plants.

3.8 *Catalytic Cracking Plant (U-21)*

The main objective of Catalytic Cracking Plant is convert heavy feed from Atmospheric and vacuum Distillation (U-10) into light oil product.

Based in general assumptions, The RDB (Reliability Diagram Block) of Catalytic Cracking Plant comprises five blocks in series which represent Preheating Feed, Conversion Subsystem,

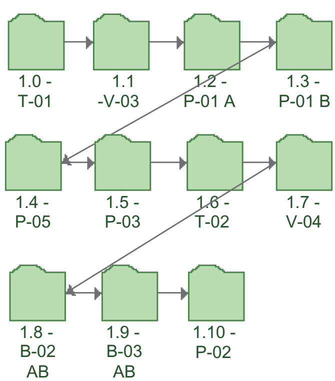

Figure 8. DEA Plant RDB.

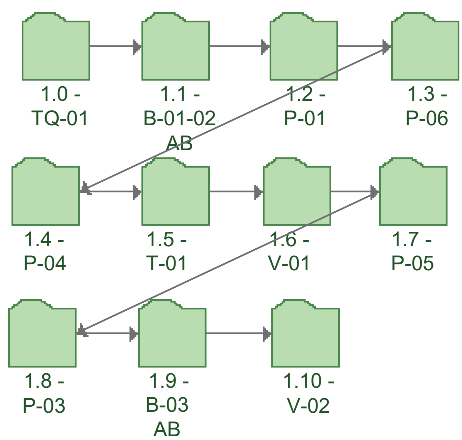

Figure 9. Acid Water Plant RDB.

Cold Area, DEA, Caustic Cleaning. That means if one of block fail down the whole RDB will be unavailable. Each subsystem represented for RDB comprises several equipments with their PDFs based in failures modes. The main assumptions to make up RDB are:

- It's not being regarded facilities availability and other supply influence in U-21 availability;
- The equipment failure modes are based in failure historical data of own Unit Plant;
- Subsystem unavailability represents system fail down;
- The availability target is 98,0% in 3 years;
- Total Production per day is 55 m^3/day.

In Figure 10 below does shown RDB which comprise five e main diagram blocks.

The most critical equipment in such plant is compressor in terms of number of increasing failures despite due to K/N (2/3) configuration, it not cause high unavailability impact in whole system.

3.9 *Reforming Catalytic Cracking Plant (U-22)*

The main objective of Reforming Catalytic Cracking Plant is convert heavy nafta from fractioning Plant (U-20) into reforming nafta product.

Based in general assumptions, The RDB (Reliability Diagram Block) of reforming Catalytic Cracking Plant comprises five blocks in series which represent Reaction, Recontact, Debutanizer, Purification and Regeneration. That means if one of block fail down the whole RDB will be unavailable. Each subsystem represented for RDB comprises several equipments with their PDFs based in failures modes. The main assumptions to make up RDB are:

- It's not being regarded facilities availability and other supply influence in U-22 availability;
- The equipment failure modes are based in reliability requirement and failures data from similar equipments;
- Subsystem unavailability represents system fail down;
- The availability target is 98,0% in 3 years;
- Total Production per day is 800 m^3/day.

In Figure 11 below does shown RDB which comprise five e main diagram blocks.

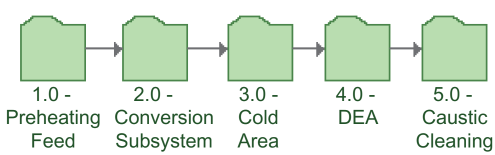

Figure 10. Catalytic Cracking Plant RDB.

3.10 *Fractioning Plant (U-20)*

The main objective of Fractioning Plant is turn out nafta from Nafta Hydrotreatment Plant (U-13) into heavy and light nafta product.

Based in general assumptions, The RDB (Reliability Diagram Block) of Fractioning Plant comprises eight blocks in series which represent towers, pumps, vase and heat exchanger. That means if one of block fail down the whole RDB will be unavailable. Each subsystem represented for RDB comprises several equipments with their PDFs based in failures modes. The main assumptions to make up RDB are:

- It's not being regarded facilities availability and other supply influence in U-20 availability;
- The equipment failure modes are based in failures data from similar equipments of other refinery;
- Subsystem unavailability represents system fail down;
- The availability target is 98,0% in 3 years;
- Total Production per day is 1500 m^3/day.

In Figure 12 below does shown RDB which comprise five e main diagram blocks.

3.11 *Logistic resources*

Logistic management is that part of supply chain process that plans, implements and control the efficient, effective flow and storage of goods, services and related information from the point of origin to the point of consumption in order to meet customer's requirement (Ballou 2004). The logistic resource like tanks, pipelines and ships have main objective to make products, equipment and raw material flow easier along process in order to maximize profits.

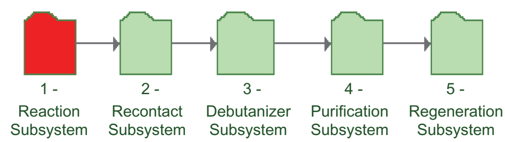

Figure 11. Reforming Catalytic Cracking Plant RDB.

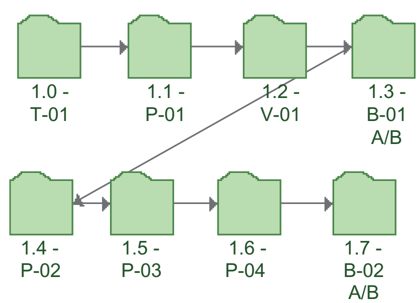

Figure 12. Fractioning Plant RDB.

The logistics recourses configuration mostly is applied to systems regarding its dependence and related demands and supply of products. In general, in Logistic model assessments is not take into account the equipment reliability which would take high influence in profits results. Even if that assumption is limited in such Logistic analysis, the other way round happen too, in other words, logistic assumption in many cases is not taking into account in RAM analysis. That is the main point that will be discuss below in a case study that will comprise Plants and logistic resources together having a Complex Refinery System.

The main logistic resources in refinery plant case study are tanks which provide oil to distillation plants. Such tanks reduce system unavailability whenever pumps or other equipment which supply oil to tank shut down. In Figure 13, a good example of logistic mixed with RDB Methodology.

In first case, both Distillation plants are feed for tanks. The U-10 is fed by G-01 and G-404. Both tanks are available and only one of them are enough to supply U-10, being G-404 an active redundancy. Into such tanks there are equipments and their failures. The RDB model Tank failures (internal and external corrosion) in series with two pumps parallel Block being one of them a passive redundancy.

In second case, U-11 is fed from G-401/402/405 or G-02 which supply U-11 and U-10 as an active redundancy. The G-401/402/405 represents k/n (1/3) configuration RDB that means at least one of three must be available to not shut down U-11.

Into tanks are represented tank's failures and pumps failures. Usually, logistic model probably represent the three tanks G-401/402/405 one by one even thought there was not flow to feed U-11.

In this example, there's no high impact in final result therefore such tank model in RDB methodology do not matter to final result but in Acid Water Subsystem, if logistic representation be carried out, only acid gas that feed such plants will be into account and it not represents plants shut down (U-10, U-11, U-12, U-13 and U-21) cause in case of Acid Water (U-26) shutdown, so many plants shutdown to.

Other good example is U-12, which furthermore than their equipment failures, Acid Water Plant shutdown, H2 make up compressor of U-13 shutdown and PSA (H2 purification) of U-22 shutdown make such plant unavailable.

If logistic methodology was carried out, probably that assumptions would not take into account, cause logistic focus in product flow. As doing so, such assumption must be represented in order to regards such impact. In Figure 14, such outside U-12 impacts are represented in RDB condition block.

Regarding such assumptions we get into conclude that is not possible to model a complex system without consider logistic and reliability issues. A refinery model example that is considered complex system with ten plants and tanks will be carried out in order to show RAM + L application.

4 SYSTEMS SIMULATION

The Simulation (Monte Carlo) has the main objective to confirm the system availability

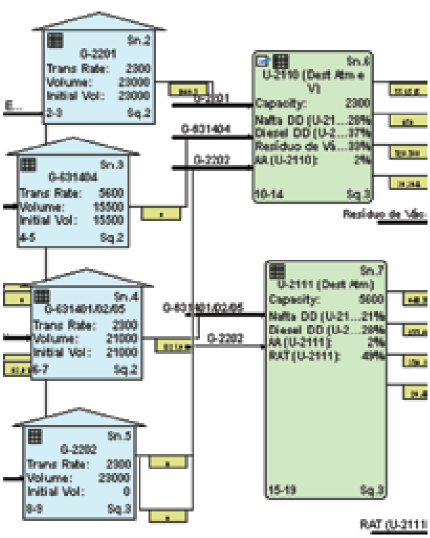

Figure 13. Tank feed distillation plants.

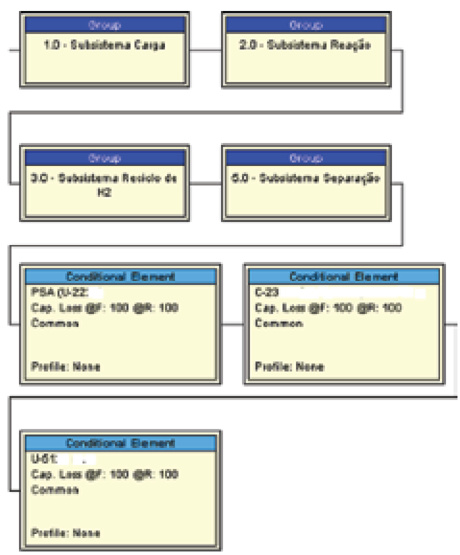

Figure 14. Outside U-12 impacts.

results in order to determine critical equipment or logistics resources (Tanks) in terms of availability and utilization to give support to improvement decisions. That RDB (Reliability Diagram Block) methodology makes up systems configuration regarding each equipment and failures modes and taking into account failure mode repair time.

For each system mentioned above is performed a simulation and after the whole system will be assessed based in RDB (Reliability Diagram Block) methodology.

In order to run simulation some software like MAROS (Maintainability, Availability, Reliability, and Operability Simulator-DNV) and BLOCKSIM (Reliasoft) are performed and final results are compared among then in order to check result.

Nevertheless, when Systems characteristics are not representing completely, it's possible to simulate the effect of equipment failures in System availability. Accord with simulation methodology it's possible to represent system life cycle along time and take into account system down time.

The systems simulations one by one were performed showing the main result. The availability and efficiency are approximately the same in case 1 and different in case 2. The cases are:

- The Case 1 regards that all equipments (in series) shutdowns cause 100% unavailable of one specific system capacity production;.
- In Case 2, partial of Plant Capacity production is loss when equipments (in series) shutdowns.

The equation below shows case 1, that availability and efficiency are the same along time. In this case production is always in two condition along time, 0% when equipments shutdown or 100% when system working property. $D(t)$ is availability, $EP(t)$ is efficiency, t is time that system is working, T is nominal time, p is real production and P is nominal production.

The equation below shows case 1, in this case the system is either up or down or available or unavailable 100% of total capacity. The case one represent most of equipments in refineries plants like towers, vases furnace and even pumps (active and passive). Whenever such equipments shutdown, cause 100% of loss production in refineries plants.

$D(t)$ is availability, $EP(t)$ is efficiency, t is time that system is working, T is nominal time, p is real production and P is nominal production.

$$D(t) = \frac{\sum_{i=1}^{n} t_i}{\sum_{i=1}^{n} T_i}$$

$$EP(t) = \frac{\sum_{i=1}^{n} p_{ti}}{\sum_{i=1}^{n} P_{ti}}$$

$$EP(t) = \frac{\sum_{i=1}^{n} pr_i \times t_i}{\sum_{i=1}^{n} Pr_i \times T_i}$$

$$EP(t) = \frac{pr_1 \times t_1 + pr_2 \times t_2 + \cdots + pr_n \times t_n}{Pr_1 \times T_1 + Pr_2 \times T_2 + \cdots + Pr_n \times T_n}$$

$$pr_1 = pr_2 = pr_3 = \cdots = pr_n$$

$$Pr_1 = Pr_2 = Pr_3 = \cdots = Pr_n$$

$$EP(t) = \frac{pr_1 \times (t_1 + t_2 + \cdots + t_n)}{\mathrm{P}r_1 \times (T_1 + T_2 + \cdots + T_n)}$$

$$pr_i = \mathrm{P}r_i$$

$$EP(t) = \frac{pr_1 \times (t_1 + t_2 + \cdots + t_n)}{pr_1 \times (T_1 + T_2 + \cdots + T_n)}$$

$$EP(t) = \frac{(t_1 + t_2 + \cdots + t_n)}{(T_1 + T_2 + \cdots + T_n)}$$

$$EP(t) = \frac{\sum_{i=1}^{n} t_i}{\sum_{i=1}^{n} T_i} = D(t)$$

The equation below shows case 2, and in this case production depends on loss that equipment cause in system range from zero to 100%. As the same, $D(t)$ is availability, $EP(t)$ is efficiency, t is time that system is working, T is nominal time, p is real production and P is nominal production. Such condition happen for instance when some heat exchanger shutdown. In some cases is possible to produce but it's necessary to reduce production while heat exchanger is being repaired.

$$EP(t) = \frac{\sum_{i=1}^{n} pr_i \times t_i}{\sum_{i=1}^{n} Pr_i \times t_i} + \frac{\sum_{i=1}^{n} p'r_i \times t_i}{\sum_{i=1}^{n} P'r_i \times t_i}$$

$$EP(t) = \frac{pr_1 \times (t_1 + \cdots + t_{n-1})}{Pr_1 \times (T_1 + \cdots + T_{n-1})} + \frac{p'r_1 \times (t'_1 + \cdots + t'_n)}{P'r_1 \times (T'_1 + \cdots + T'_n)}$$

$$pr_i = Pr_i$$

$$p'r_i = P'r_i$$

$$EP(t) = \frac{pr_1 \times (t_1 + \cdots + t_{n-1})}{pr_1 \times (T_1 + \cdots + T_{n-1})} + \frac{p'r_1 \times (t'_1 + \cdots + t'_n)}{p'r_1 \times (T'_1 + \cdots + T'_n)}$$

$$EP(t) = \frac{(t_1 + t_2 + \cdots + t_n)}{(T_1 + T_2 + \cdots + T_n)} + \frac{(t'_1 + t'_2 + \cdots + t'_n)}{(T'_1 + T'_2 + \cdots + T'_n)}$$

$$EP(t) = \frac{\sum_{i=1}^{n} t_i}{\sum_{i=1}^{n} T_i} + \frac{\sum_{i=1}^{n} t'_i}{\sum_{i=1}^{n} T'_i} = D(t) + D'(t)$$

Looking at Table 2 we conclude that the most critical systems are CTB, CCR, Nafta HDT and Diesel *HDT* because lowest efficiency value than defined target.

Regarding RDB methodology, refinery availability will be lower than the lowest system availability because the systems are in series. That the same regarding efficiency. In fact, that a very conservative_ assumption and it can be used to represent complex Systems which comprise all systems and it means that in case of shutdown in any System the whole Complex System will shut down. In this case, refinery efficiency is lower than 95,77% over the 3 years period. The results will be improved if improvement are implemented on each critical system. By the other way round, regarding logistic resources and model Complex System which comprise tanks and plants, in case of plant or tanks shut down, other products are produced even though such shutdown occur. That is RAM + L approach, which consider reliability and logistic to make up complex model that is different from RDB (reliability Diagram Model) approach which consider all plants in series and tanks in parallels. In next analysis, improvements actions will be used to compare RAM + L results with RAM Methodology results.

Table 2. System efficiency.

System	Efficiency target	Efficiency result
UDA	98,0%	100%
UDV	98,0%	100%
UFCC	98,0%	100%
AA	98,0%	100%
DEA	98,0%	100%
CTB	98,0%	95,74%
CCR	98,0%	97,44%
Fractioning	98,0%	99%
Nafta HDT	98,0%	95,77%
Diesel HDT	98,0%	97,64%

5 CRITICAL ANALYSIS AND IMPROVMENT ACTIONS

Regarding system results, the CCR, CTB, Nafta HDT and Diesel HDT are the most critical plants. Therefore improvements are to be carried out on systems to eliminate failures or reduce the consequences therefore improving system efficiency and consequently Complex System efficiency.

On CCR the most critical equipment are reactors due to linkage failure modes therefore the system improvement action is:

- To propose procedures when plant will buid up to avoid linkage in such equipments;

On CTB plant the most critical equipment is the furnace due to coke formation therefore the system improvement action are:

- To reduce decoke time time spalling on line procedure will be carried out in order to reduce time to decoke furnace and reduce unavailability time;

On Nafta and Diesel HDT the most critical equipment are reactors due to linkage failure modes therefore the system improvement action is:

- To propose procedures when plant will build up to avoid linkage in such equipments;

These improvement actions will results in efficiency improvements as shown in Table 3 below.

After all systems improvement is necessary to make up the macro system regarding all plant in series based in RDB (Reliability Diagram Block) Methodology). As doing so, the macro system availability is 93,89% in 3 years and it configuration is shows in Figure 15 below.

That result represents that refinery will produce 93,89% of total production (3 years) in their higher capacity. In fact, such conservative approach required a RAM + L Methodology configuration that will be carried out on next item regarding logistic issues (tank) and reliability.

6 RAM + L SIMULATION

The RAM + L methodology consider logistic resources in Complex System efficiency and make up

Table 3. System efficiency improvement.

System	Efficiency target	Efficiency result
UDA	98,0%	100%
UDV	98,0%	100%
UFCC	98,0%	100%
AA	98,0%	100%
DEA	98,0%	100%
CTB	98,0%	98,53%
CCR	98,0%	98,26%
Fractioning	98,0%	99%
Nafta HDT	98,0%	99,05%
Diesel HDT	98,0%	98,56%

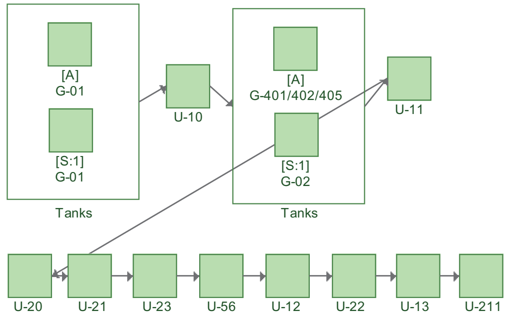

Figure 15. Macro system RDB configuration.

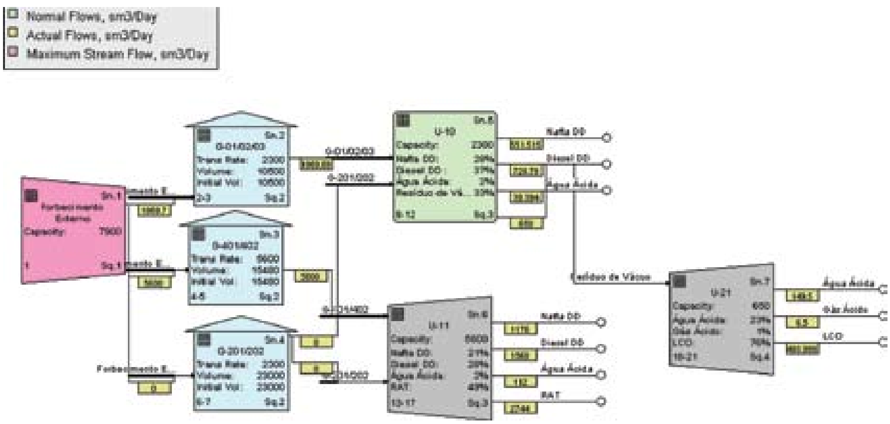

Figure 16. Actual refinery (RAM + L).

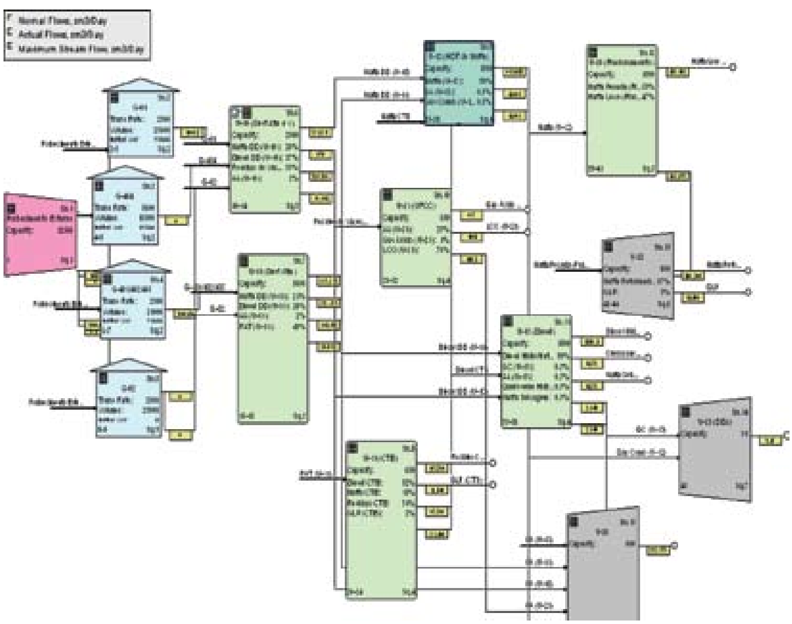

Figure 17. Actual refinery (RAM + L).

model which consider both logistic and equipment failure. The final results will show the total efficiency in all products regarding the relation between demand and supply among equipments and systems.

The whole system will be represented actual and future configuration as shows Figure 16 and 17 in page 14 below. The actual refinery configuration comprises seven tanks and three plants (U-11, U-10 and U-21). The future configuration consider more seven Plants (U-56, U-23, U-12, U-13, U22, U-20, U-211).

In such configuration, the U-56 is in series with U-10, U-11, U-211 and U-21, it means that in case of unavailabity in such plant the other plants will shut down.

The second important condition is that PSA in U-22 supply H2 to U-12 and U13. It means that in case of PSA unavailability, U-12 and U-13 will shut down.

The third important condition is make up compressor in U-13 supply H2 to reactor in this plant (U-13) and to U-12 reactor. In case of compressor unavailability both plants will shutdown, therefore such compressor is in series with two plants (U-12 and U-13).

The final Complex System efficiency is 100% in 3 years for all products in actual configuration (Tanks, U-10, U-11 and U-21).

The final Complex System efficiency in future will vary from 99,14% to 99,86% of total production in 3 years. The result is different of RDB methodology that is not consider logistic resources (tanks and pumps) neither all products.

7 CONCLUSIONS

The RAM analysis methodology comprises logistic issue into RAM analysis being more robust assessment of Complex system like refineries.

In order to perform such analysis is required to obtain so many information about equipment failures and to define the logical dependency of systems, equipments and logistic resources.

Although is more realistic analysis commonly in Brazil is rare implemented such assessment due lack of information or integrated system vision.

In general two groups work with different issues as logistic and reliability trying to optimize Complex Systems and equipments by itself without an integrate perception.

In general, there are many software focus on system reliability or system logistic giving more importance in one or other aspect without take into account both issues. In case of more focus on reliability issues, partially solution for Complex System will achieve high availability plant but lower efficiency due logistic problems. In case of focus on logistic issues partially solution for Complex System will achieve high utilization in logistic resources with low efficiency due lower availability plants.

Some softwares like MAROS and BlockSIM softwares focus on reliability issues. By the other side, there are others software focuses more in logistic like ARENA and TARO software focus on logistic issues. The best solution is develop some software which comprise reliability and logistic issues like TARO and MAROS, improve logistics softwares like ARENA to consider reliability issues or improve reliability softwares like Blocksim to consider logistic issues.

In case study mentioned above the logistic issues were simple to be represented but if it would have been considered ships and other logistic resources it would be harder to be modeling for such software. The most important aspect is consider logistic and reliability issues when Complex System is being assessed in order to have a more reliable optimizations and improvements.

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