Sulphur Free Diesel optimiser

A decision support tool for process optimisation and an organisational review of sulphur free diesel production

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Public version

Preface

In your hands you find the final work of my academic education at the Faculty Technology, Policy and Management of the Delft University of Technology. This research was done as part of my graduation project, which was carried out for Oil & Co Refinery.
[Due to the confidentiality of the content of the full report, this public version applies fictitious names and numbers].

Readers interested in the results of this project are recommended to read the Abstract and chapters 8 and 10. For the research set-up go to chapter 3. Readers interested in organisational aspects of this project I refer to §2.2.3 and chapter 9. For the process optimisation read chapter 4 to 7. Readers unfamiliar with the refining industry are referred to chapter 2.

I would kindly thank all members of my graduation committee for their contribution to my graduation project:

- Drs. John Doe, economist of the staff department Refinery Economics and Planning of the Oil & Co refinery for his weekly, positive and profound counselling.
- Dr.ir. Zofia Verwater-Lukszo, senior lecturer of the section Energy and Industry of the Faculty of Technology, Policy and Management of the Delft University of Technology, for her stimulating and constructive advice at the moments I needed it.
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Abstract

The Oil & Co group increases the pressure on refineries to generate more profit. The introduction of the sulphur free diesel production deteriorates that pressure as the necessary adjustments result in additional costs and require downgrading of sulphur rich products. To minimise the loss of margin and cope with the limitations of the sulphur free diesel (SFD) production, a decision support tool was developed for Oil & Co refinery that maximises the margin related to diesel, taking into account blend values, deactivation costs, product specifications and quality margins, but also considers the organisational complexity. By including both the blend values and the deactivation costs, this decision support tool (called the SFD optimiser) combines the interests of the economics and planning departments as well as the interests of the production unit responsible for the desulphurisation of light gas oil, the main component of sulphur free diesel.

The SFD optimiser consists of an optimisation model that maximises the SFD optimiser margin, which is the total blend value of the diesel components minus the deactivation costs due to desulphurisation of light gas oil. At all times the product specifications must be satisfied. The optimisation problem formulated was a static, continuous, nonlinear optimisation problem with nonlinear constraints and was relatively small. The optimisation problem was solved employing the generalised reduced gradient algorithm and was implemented in GRG2, using Microsoft Excel and its Solver option. The end result is an off-line decision support tool that passes the tests of verification and validation, which can count on the confidence of OCR personnel. Moreover the SFD optimiser is reliable, easy to use and leads to significant gains. The potential monetary gains are estimated on a raise in refinery margin by 6.3 $c/bbl.[1] Non monetary gains are improved decision-making and a possible contribution to the good relation between the refinery economics and planning department and the production units. To realise all potential gains three requirements should be satisfied:

- A high level of communication and cooperation between all actors involved in the diesel production. The SFD optimiser contributes to the relation between actors.
- The performance assessment system should not only consider the achieved performance itself, but also the process of achieving that performance.
- The SFD optimiser should be kept up to date and well-maintained to maximise the life span of the SFD optimiser.

If all these requirements are satisfied, the incorporation of the SFD optimiser in the Oil & Co Refinery's organisation is successful and the realisation of the potential gains is assured.

[1] This estimate is based on prices at the end of 2004.

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Abbreviations

AGO	Automotive Gas Oil, diesel grade with a sulphur specification of 350 ppm sulphur
ASTM	American Society for Testing and Materials
bbl	barrel(s)
CDU	Crude Distilling Unit
CFPP	Cold Filter Plugging Point
CP	Cloud Point
CRD	Causal Relation Diagram
$c	US Dollar cents
Des-	Desulphurised
EN	European Norm
FP	Flash point
GHP	Gasification Hydrogen Plant
GMI	Global Margin Improvement
HCU	Hydro Cracking Unit
HDS	Hydro Desulphuriser
HGO	Heavy Gas Oil
HSC	High Sulphur Components
HVU	High Vacuum Unit
IDEF	Integrated Definition
IGO	Industrial Gas Oil
ISO	International Organization for Standardization
Kero	Kerosene
LEM	List Extension Method
LGO	Light Gas Oil
LO	Low Olefins
OCR	Oil & Co refinery
PU	Production Unit
ppm	part per million
QMI	Quality Measuring Instrument
RTC	Refinery Treating and Conversion, production unit
RUD	Refinery Utilities and Distillation, production unit
RCP	Refinery Cracking and Power, production unit
RPC	Refinery Process Control, staff department
RBL	Refinery Blending and Logistics, production unit
REP	Refinery Economics and Planning, staff department
RT	Refinery Technologists, staff department
S	sulphur
SBP	Special Boiling Product
SMOC	Super Multivariable Optimising Controller
COT	Claus Off-gas Treating
SFD	Sulphur Free Diesel, diesel grade with a sulphur specification of 10 ppm sulphur
SRU	Sulphur Recovery Units
T95	Temperature at which 95% of volume is recovered in the distillation process
TGI	Thermal Gas oil Installation
TU	Technical University
ULSD	Ultra Low Sulphur Diesel, diesel grade with a sulphur specification of 50 ppm sulphur
WABT	Weighted Average Bed Temperature

1 Introduction

Since the seventies the European Union, together with the petroleum industry, aims to reduce the negative environmental impact of the use of hydrocarbon fuels. A part of this effort focuses on the reduction of sulphur in fuels. This year fiscal incentives are imposes to stimulate the production of sulphur free diesel (SFD), a diesel grade which contains at most ten sulphur parts per million. One of the Dutch refineries that are going to produce sulphur free diesel for the Dutch market is Oil & Co Refinery (OCR). To be capable to produce SFD many adjustments in the refinery were made, which changed the diesel production significantly. As some plants need to be driven to extreme operational conditions, the production process of diesel becomes more critical. Besides technical aspects the introduction of SFD also has some economic consequences. Revenues drop as many former diesel components cannot be used for the diesel production anymore and should be downgraded. Moreover the operational costs go up as the costs of desulphurisation rise. Hence refinery margin decreases and this is ill news as the pressure to raise refinery margins is high in the Oil & Co group. Oil & Co is short of oil reserves and to restore these reserves a lot should be invested in exploration. These investments should be (partly) paid with the refinery margins. In short, the introduction of the sulphur free diesel increases the pressure on the refinery margin. To cope with the critical operational conditions and minimise the loss of margin the refinery's economics and planning department would like a decision support tool that optimises the diesel production.

Goal of this research is to develop a decision support tool that optimises the production of sulphur free diesel.[1] The decision support tool is considered successful if it leads to significant gains and these gains are realised. To be successful the process optimisation should, besides concentrating on the optimisation aspects, also take into account the organisational complexity and consider the chance of successful incorporation of the decision support tool. The decision support tool, called SFD optimiser, determines the production settings that maximise profit, including catalyst lifecycle economics in the decision-making process and assuring that at all times all product specifications are met.
The development of the decision support tool consists of the three steps:

› Conceptualisation: reducing problem complexity by applying conceptualisation methods like activity-based analyses (IDEF0) and Causal Relation Diagrams.
› Specification: model specification includes formulating model specifications, describing the optimisation problem in qualitative terms, identifying data requirements and formalisation of the optimisation problem.
› Validation, verification and sensitivity analysis.

The second part of the research aims at mapping the organisational incorporation of the decision support tool, in other words shows the chance of a successful implementation of the SFD optimiser. First some theoretical notions are used to examine the complexity of the refinery's organisation. Then the incorporation of the process optimisation is discussed. Finally a conclusion is drawn regarding the chance of successful incorporation.

This research report consists of ten chapters. Chapter 2 elaborates more on both the current and future diesel production. In the subsequent chapter, Chapter 3, the research set-up is described. Chapter 4 contains an organisational survey. Chapter 5 conceptualises the technological problem. After conceptualisation the model can be specified (Chapter 6) and validated (Chapter 7). Chapter 8 deals with the implementation and gains of the optimiser. Chapter 9 handles the organisational incorporation of process optimisation. Chapter 10 summarises the findings and provides some further recommendations.

[1] Gasoline falls outside the scope of this research.

2 Situation sketch

This chapter gives an introduction to the current and future diesel production at the Oil & Co Refinery (OCR). In the fist paragraph the background of the sulphur reduction is explained. The second paragraph deals with basic knowledge about diesel. The second paragraph provides some background information about OCR. The third paragraph sketches the current diesel production at OCR. The fourth paragraph deals with the future diesel production, pointing out the opportunities for improvement.

2.1 Reason for sulphur reduction

The Netherlands was, together with France, Italy and Germany, the first country that laid down a standard on sulphur content in law. In 1974 these countries introduced a national sulphur specification that measured 7000 mg/kg. The first European sulphur specification goes back to 1976 and stated a sulphur content of 5000 mg/kg [Directive 75/716/EEC]. That was the start of the engagement of the European Union to reduce the sulphur content in on road fuels. As indicated in the introduction the subject of this research is the sulphur free diesel production at Oil & Co Refinery. Diesel is a mixture of hydrocarbons that boil at temperatures between ca. 160°C and 360°C and is, besides gasoline, one of the on road fuels. It has many properties, amongst which sulphur content. The sulphur in fuels should be reduced for two reasons:

› Modern motor technology applies catalysts that perform optimally at sulphur poor fuels [Directive 2003/17/EC].
› The combustion of sulphur leads to the emission of sulphur oxides, which cause acid rain and breathing problems for humans and animals

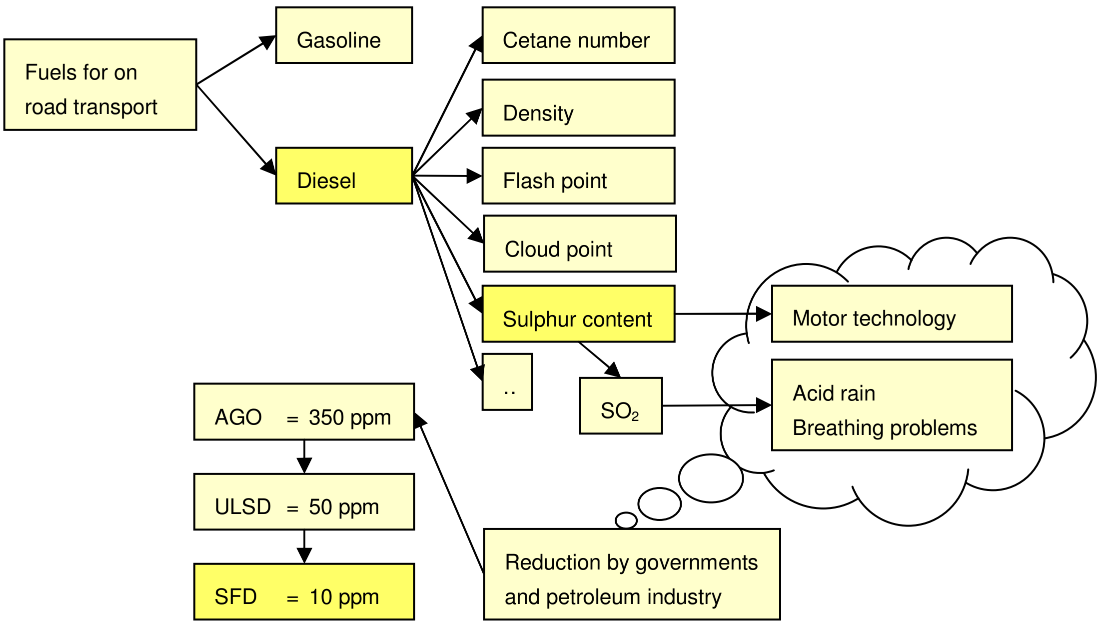

Figure 1 Background of sulphur reduction

Since the nineties three diesel grades are known:

› Automotive Gas Oil (AGO), which has a sulphur specification of 350 mg/kg, i.e. 350 parts per million (ppm). Standard since 2000
› Ultra Low Sulphur Diesel (ULSD), which has a sulphur specification of 50 mg/kg, i.e. 50 ppm. At the moment this is the European standard.
› Sulphur Free Diesel (SFD), which has a sulphur specification of 10 mg/kg, i.e. 10 ppm. The standard from the 1st of January 2009. At this moment this standard is already put into action in Germany.

Now we are in a period of transition, transition between the last two diesel grades. Till the 1st of January 2009 the Ultra Low Sulphur Diesel specification of 50 ppm is European standard operative. All member states have committed themselves to be capable to produce sulphur free diesel by the 1st of January 2005. Thus from this date onwards the refineries present in the member states should have adjusted their equipment for the sulphur free diesel production. To stimulate the introduction of sulphur free diesel before 2009 some member states decided to impose fiscal incentives from 2005 onwards. The Dutch government is going to put such incentives into action on the 1st of July 2005 [Staatsblad van het Koninkrijk der Nederlanden, June 15th 2004]. This penalty makes it economically more attractive for the Dutch refineries to start the sulphur free diesel production already this year. For Oil & Co Refinery this switch resulted in major changes in the refinery, see §2.3 and §2.4.

2.2 Diesel properties and specifications

The only difference between ultra low sulphur diesel and sulphur free diesel is the sulphur specification. Table 1 summons the main properties of both diesel grades. The other properties were of lesser or no importance to this research project.

Table 1 ULSD and SFD specifications [European Standard EN 590:2004]

Properties	**ULSD**		**SFD**	
Colour	Max. 2,0			
Density at 15°C	min. 820 kg/m³ max. 845 kg/m³			
Flashpoint, FP	min. 55°C		Min. 59°C *	
Sulphur Content	max. 50 mg/kg		max. 10 mg/kg	
Distillation temperature at which 95% (V/V) is recovered, T95	max. 360°C **			
Cold flow properties	**15.04.-14.09**	**15.09.-31.10.**	**01.11.-29.02.**	**01.03.-14.04.**
Cloud Point, CP	+ 5	- 3	- 7	- 3
Cold Filter Plugging Point, CFPP	- 2	- 13	- 25	- 13

* Officially the European flash point specification is at least 55°C, but the German specification for FP is stricter, namely 59°C. Reason for this stricter specification is the fact that a significant amount of diesel is transported to Germany through pipeline, where it can be contaminated. To compensate for this potential contamination the stricter specification is applied.

** Later on in the report is explained that the specification for distillation temperature (T95) is going to be of small importance for the sulphur free diesel production at Oil & Co Refinery, because the diesel components are going to be distilled on lower temperatures to unburden desulphurisation capacity. In the future the T95 specification applied within OCR is 345°C.

The main properties of interest in this project are further explained below [www.dieselnet.com]:

Colour: Colour is an indicator for contamination and ageing of fuel. It is an index starting at zero (transparent) to 28 (black). One sort of contamination, relevant to this project, is the presence of cracked material, which causes a green colour.

Density: Fuel injection systems run on basis of volume, so a change in density has impact on the engine power. To guarantee stable engine performance the density of fuel should not vary extremely.

Flash point	Temperature at which a combustible liquid gives off just enough vapour to produce a vapour/air mixture that will ignite when a flame is applied. The flash point is measured in a standardized apparatus using standard test methods (ISO 2719).
Sulphur content	Combustion of sulphur causes environmental and health problems, and raises problems for modern motor technology. That's the reason the sulphur content is restrained. Because of the lubricative effect of sulphur additives need to be added in order to maintain sufficient lubricity of diesel fuel.
T95	Temperature at which 95% of volume is recovered in the distillation process.
Cloud point	Measure of the ability of a diesel fuel to operate under cold weather conditions. Defined as the temperature at which wax first becomes visible when diesel fuel is cooled under standardized test conditions (ASTM D2500).
CFPP	Measure of the ability of a diesel fuel to operate under cold weather conditions. Defined as the lowest temperature at which diesel fuel will pass through a fine wire mesh screen of the test apparatus (EN 116). The CFPP can be increased by adding certain additives.

2.2 Oil & Co Refinery

Because some readers might be unfamiliar with refining processes and the OCR organisation this paragraph provides some background information about the refinery (§2.2.1) and its organisation (§2.2.2).

2.2.1 <u>Refinery basics</u>

In OCR crude oil is processed into a wide variety of products, both end products and intermediate products. OCR is not only known because of its size, but also because of its high flexibility: a variety of both light and heavy crude can be processed here.
The units relevant to diesel production are:

› Crude Distilling Unit (CDU): can be seen as the start of the refining chain. It distils crude oil to several products, e.g. kerosene, light gas oil and heavy gas oil. The residue of the distilling units is called long residue.
› High Vacuum Unit (HVU): distils the long residue to, among others, waxy distillates.
› Hydro Cracking Unit (HCU); further processes the waxy distillates. One of the effluent products is gas oil. HCU gas oil is a diesel component.
› Hydro Desulphuriser (HDS): removes sulphur from product streams. This unit can reduce the sulphur content from several percentages to several parts per million (ppm).

There are many other units located on the OCR site, but they are not (directly) utilised for diesel production and thus fall outside the scope of this project.

Products relevant to this project are:

› Kerosene: a CDU distillate. Main component for airplane fuel (named Jet A1).
› Light Gas Oil (LGO): a CDU distillate, a heavier oil fraction than kerosene
› Heavy Gas Oil (HGO): a CDU distillate, a heavier oil fraction than light gas oil
› HCU Gas Oil (HCU gas oil): one of the hydro cracker effluents
› Ultra Low Sulphur Diesel (ULSD): the diesel quality with a sulphur specification of 50 ppm (see §2.1).
› Sulphur Free Diesel (SFD): the diesel quality with a sulphur specification of 10 ppm.
› Industrial Gas Oil (IGO): fuel for tractor vehicles and industrial purposes.
› Jet A1: fuel for airplanes

- Special Boiling Product – Kerosene (SBP Kero): kerosene with a sulphur content of 2 ppm, which is much lower than the Jet A1 sulphur specification of 3000 ppm.
- Feed for Low Olefins (LO feed): in the current situation this is not related to the diesel production but in the future situation it is going to be (see §2.4.2 and §2.4.3).
- High Sulphur Components (HSC): in case of a HDS upset the light gas oil cannot be desulphurised and the gas oil needs to be downgraded to the high sulphur components pool, as the gas oil has a sulphur content higher than the specification of the industrial gas oil.

The rest of the products processed on the OCR site are not relevant to this project and will not be considered.

2.2.2 Hydrodesulphurisation units

One of the central units in this research project is the hydrodesulphurisation unit (HDS). The HDS process consists of several steps; in sequential order:[1]

- Preheating feed by heat exchangers.
- Heating feed by furnace.
- Reacting in the reactor, where a catalytic reaction takes place.
- Cooling down by heat exchangers.
- Separating product from other components, done by high-pressure separators, low-pressure separators, strippers and dryers.
- Sulphur removal from recycle gas, done by an amine scrubber, sulphur recovery units (SRU) and Claus off-gas treaters (COT)

After these processes the product is desulphurised, separated from other components and ready to be blended in the end product pool.

The actual desulphurisation takes place in the HDS reactor where sulphur rich hydrocarbon molecules react with hydrogen to sulphur poor hydrocarbon molecules and H_2S. This is a catalytic reaction. The H_2S component is removed from the hydrocarbons in the separation step.

The level of desulphurisation depends on the catalytic activity, which is determined by the Weighted Average Bed Temperature (WABT) and the hydrogen partial pressure (ppH_2). The latter depends on the operating pressure in the HDS reactor and the purity of the hydrogen rich treat gas. The desulphurisation level also depends on the sulphur content in the feed, the time the hydrocarbons are in the reactor and the complexity of the sulphur compositions.

During the desulphurisation process the catalyst degrades as a result of deactivation phenomena (e.g. sintering, fouling, poisoning and attrition) [Bartholomew, 2001; Lauritsen et al, 2004]. Deactivation is expressed in a rise of WABT per time. A degradation rate of 2^oC per month means that for the same level of desulphurisation the WABT needs to be raised by 2^oC per month. The lifetime of a catalyst, also called run length, is determined by the maximum WABT. When the WABT reaches its maximum the catalyst can be replaced or throughput can be reduced. The run length of catalysts used for desulphurisation in the HDS's varies between one and two years, depending on the level of desulphurisation realised and possible upsets in operations, like furnace trips.

2.2.3 Refinery organisation

Oil & Co Refinery (OCR) consists of circa twenty departments, which are referred to as actors. An organisation chart can be found in Appendix 1. This paragraph discusses in more detail the seven actors involved in the diesel production. A distinction can be made between production units, directly involved in the production process, and staff departments, which are not involved directly [Mintzberg, 1983]. For every actor a short description is given of its tasks and responsibilities.

[1] In Appendix 4 the HDS process is analysed using the IDEF0 method, see also §5.1.

Three staff departments are involved in the diesel production:

1. Refinery Economics and Planning (REP): schedules the refinery and trading hydrocarbon activities. Leading principles are that, within agreed operation time horizon and preconditions, the specified needs of customers are satisfied completely and that margin is generated from the available resources, as effectively as possible. This requires intensive contact of the department REP with operational, technological, trading, central planning and logistic departments. REP coordinates with regard to OCR economics, logistics, production possibilities and product specifications. REP's main task is to maximise the refinery margin within the framework of the refinery's key performance indicators. Clearly REP is one of the main actors in this research project.

2. Refinery Process Control (RPC): provides technical expertise to production units and project departments regarding instrumentation, (advanced) process control and on-line optimisation. RPC is mostly involved indirectly as it consults other actors. For that reason RPC is not considered a main actor.

3. Refinery Technologists (RT): looks at long-term developments that will influence OCR regarding technology, energy and environment and is involved in the management of site-wide systems. Although RT possesses a great deal of technical expertise, they are considered a facilitating department and not one of the main actors.

Four of the five production units are involved in the diesel production:

1. Refinery Utilities and Distillation (RUD): core activities of RUD are to produce, in consultation with REP and according customer specification, products in a controlled, safe, environment-friendly, effective and efficient manner, and manage (maintain) installations. For the diesel production relevant RUD units are CD/5, CD/6 and HDS/4.

2. Refinery Treating and Conversion (RTC): core activity of RTC is to produce, in consultation with REP and according to customer specification, gaseous and liquid hydrocarbons in a controlled, safe, environment-friendly, effective and efficient manner, from the effluent flows of other production units. For the diesel production relevant RTC units are HDS/1, HDS/2, HDS/3, Sulphur Recovery Units (SRU) and Claus Off-gas Treating (COT).

3. Refinery Cracking and Power (RCP): core activities are:
   - To produce and internally provide, in consultation with REP and according customer specification, gaseous, vaporous and liquid components in a controlled, safe, environment-friendly, effective and efficient manner, from the effluent flows of other production units.
   - To produce steam and electricity for the whole site and distribute utilities (steam, electricity, natural gas, air, water and condensate).
   - To manage the SO_2-emissions, the high chimney and several tanks.

   For the diesel production the relevant RCP unit is the Hydro Cracking Unit.

4. Refinery Blending and Logistics (RBL): performs, in consultation with REP, the following activities:
   - Receive, store and transport intermediate products
   - Prepare feed for other production units' plants
   - Blend different product streams

- o Store, transport and deliver end products
- o Manage the maintenance of tanks

For the diesel production relevant RBL activities are blending and transporting products.

Not all actors involved are of the same level of importance with regard to the development of the process optimisation. Regarding the staff departments involved, RPC and RT tasks are mostly of a facilitating nature and therefore of lesser importance to this research project. As all four production units are directly involved in the diesel production, they are all considered main actors.
Thus the main actors in the diesel production are REP, RUD, RTC, RCP and RBL. These five actors together are responsible for the desulphurisation of kerosene, the sulphur content of the HDS effluent, the production of HCU gas oil, the blending and being on spec of the diesel and the margin realised.
Earlier the distinction between staff departments and production units was mentioned. This distinction is related to the way these actors' performance is assessed. Oil & Co Refinery employs key performance indicators for this assessment. The four key performance indicators are:

› Health, Safety and Environment (HSE): the number of incidents with human injuries and the number of incidents with loss of containment
› Operational availability: the percentage of the time units are available for operation
› Margin: gross refinery margin in million US dollars
› Costs: costs made in million Euros[1]

The emphasis and relevance of these KPI's differs for different actors. The production units, for instance are mostly assessed on HSE, OA and costs, while REP has to account mostly for margin. This difference in assessment results in a different perspective as it comes to economic performance. REP has clearly a margin-focus and the production units, on the other hand, have a cost-focus. This difference in perspectives should be included in an optimisation model. Neither the revenues should be maximised nor should the cost be minimised, rather the margin should be optimised, so the overall OCR performance will be optimised.
Further discussion on the organisation can be found in chapter 4 and 9, where the consequences of the introduction of the process optimisation tool, the SFD optimiser, are discussed.

2.3 Current diesel production

This paragraph will briefly describe the current situation at OCR. The first subparagraph, §2.3.1, sketches the current diesel production. The second subparagraph, §2.3.2, describes the RBL AGO blender, a new system that recently was introduced in operation.

2.3.1 <u>Ultra Low Sulphur Diesel production</u>

At present the European norm for sulphur in diesel corresponds to the ULSD specification, being 50 ppm. In Germany on the other hand the SFD specification of 10 ppm is already operative. At present OCR has chosen to import SFD to satisfy the German demand rather than producing it themselves. Currently the full diesel production capacity of OCR is used to produce ULSD.
For the ULSD production four input flows are processed (see Figure 2):

› Kerosene (Kero): indicated in blue
› Light Gas Oil (LGO): indicated in green
› Heavy Gas Oil (HGO): indicated in red

[1] The corporate finance currency is US dollars, but costs are expressed in the local currency, Thus for OCR costs are expressed in Euros.

- Hydro Cracking Unit Gas Oil (HCU gas oil): indicated in purple
- Blends of components: indicated in black

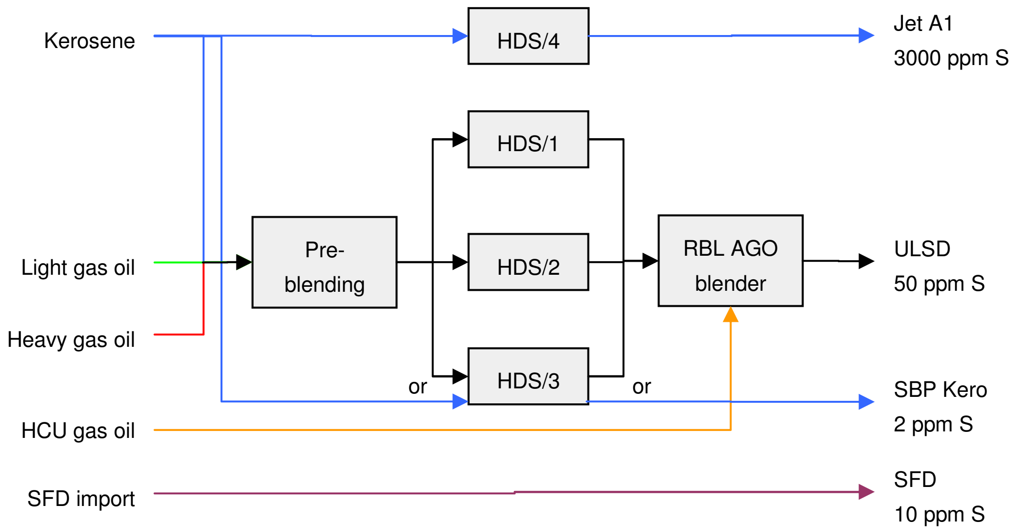

Figure 2 Present diesel production

This figure is clarified below by describing the end product.

- Jet A1: the main component of Jet A1 is kerosene which is desulphurised by HDS/4
- ULSD: diesel components are kerosene, light gas oil, heavy gas oil and HCU gas oil. Before desulphurisation kerosene, light gas oil and heavy gas oil are blended, the so-called pre-blending. The heavy gas oil is of lesser quality than light gas oil. To compensate for the properties of this heavier fraction, the lighter Kero is added. The production unit responsible for the pre-blending and the quality of the HDS feed is RUD. The HDS feed must be within ULSD specification. After pre-blending the mixture is desulphurised by the HDS's. The resulting sulphur content is within the 50 ppm specification. After desulphurisation HCU gas oil is added for economic reasons. HCU gas oil should otherwise be downgraded to the industrial gas oil for much lower prices. A second blender, the RBL AGO blender, determines the quantity of HCU gas oil that can be blend into the ULSD pool (see §2.3.2).
- SBP Kero: HDS/3 is, besides for the desulphurisation of light gas oil, also utilised to desulphurise kerosene to 2 ppm. HDS/3 is alternately used for the production of diesel and SBP Kero. The number of days a month that HDS/3 is utilised for SBP Kero production varies, but is generally speaking smaller than the number of days this unit is utilised for the desulphurisation of light gas oil.
- SFD import: the sulphur free diesel for the German market is sold on the Rotterdam market and directly pumped to Germany by pipeline.

2.3.2 RBL AGO blender

As shown in Figure 2 HCU gas oil is added to the ULSD pool after desulphurisation of LGO. This blending is automated and is installed in 2004 in consideration of the SFD production. The production unit responsible for blending is Refinery Blending and Logistics (RBL). The internally used name for this blender is the RBL AGO blender. A scheme of this blender can be found in Appendix 2.

The RBL AGO blender takes into consideration sulphur content, density and flash point, because in the future SFD production those are the constraining properties. The density and flash point of the HCU gas oil are always within the ULSD specifications. The quantity of HCU gas oil to be blended into the ULSD pool depends on the sulphur content of the HCU gas oil.

Figure 3 Sulphur content in HCU gas oil

Due to catalyst degradation the sulphur content of the HCU gas oil gradually increases during the HCU catalyst run length of four years. In the current ULSD production the sulphur content of HCU gas oil is mostly below the ULSD specification and thus the complete quantity of HCU gas oil can be blended in the ULSD pool. In the future SFD production the quantity of HCU gas oil becomes sulphur constrained.

2.4 Future diesel production

The description of the ULSD production, as given in the former paragraph, is still applicable to the current operation of the OCR site. The future diesel production, the SFD production, will be introduced mid-2005.
This paragraph elaborates on the future SFD production. The best practices for SFD production are summoned (§2.4.1) and paragraph 2.4.2 discusses which practices are implemented by OCR. The third paragraph, §2.4.3, elaborates on the new set up of the diesel production, after which two systems will be explained (§2.4.4 and §2.4.5). The last paragraph, §2.4.6, identifies opportunities to improve the diesel production, which forms the starting point for this project.

2.4.1 <u>Best practices in theory</u>

Theory about the sulphur free diesel production mentions a number of best practices for SFD production [Lee and McGovern, 2001; Low et al; Reinhardt et al, 2002, Rouby et al, 2003; Street et al 2003; Swain and Allen, 2004; Torrisi and DiCamillo, 2002; Torrisi et al, 2003; Torrisi and Gunter, 2004]:

› Manage feed quality: the quality of the crude oil processed by the crude distilling units is an essential factor to the refinery's flexibility. The lower the sulphur content in the crude, the more easily SFD can be produced. Crude buyers already make a distinction between low sulphur and high sulphur crude. Next to the feed for the crude distillers, it is also an option to alter the feed of units further down the refining process. A unit, for instance, can be given a lighter feed, which is easier to process.

› Manage dispersion: another way to lower the sulphur content in the desulphurisation unit's feed is to distil the crude oil differently. The more complex sulphur molecules that are the hardest to remove, are present in the heavier oil fractions. By undercutting the light gas oil fraction, in other words cutting the light gas oil on lower temperature, these complex sulphur molecules are removed from the light gas oil fraction to the heavy one. This undercutting enables the desulphurisation units to desulphurise the HDS feed to the desired level.

› Upgrade to new catalyst: desulphurisation is a catalytic process. A self-evident way of improving the HDS process is by employing a better catalyst. In recent years many catalyst suppliers have introduced more powerful catalyst, suited for SFD production.

› Increase hydrogen partial pressure (H_2pp): sulphur is removed by absorption of sulphur to hydrogen. An indicator of the ease of this adsorption is the hydrogen partial pressure. This variable depends mainly on the reactor pressure and the hydrogen content in the treat gas. The hydrogen content in the treat gas depends on the purity of the recycling gas (see next best practice) and the purity of the fresh hydrogen added.

› Remove H_2S from recycle gas: as already mentioned the purity of the treat gas determines the hydrogen partial pressure, which is a key variable in the HDS process. In many refineries the treat gas is separated from the product stream and recycled to the HDS reactor. Unfortunately the treat gas is polluted. The sulphur reacts with the hydrogen to the gaseous H_2S. If H_2S is not removed the hydrogen purity of the treat gas decreases and, thus, also the hydrogen partial pressure drops. By removing H_2S from the treat gas the hydrogen partial pressure is increased.

› Use combinations of catalysts to handle complex sulphur aromatics: new technology makes it possible to employ not a single catalyst for desulphurisation but rather use a combination of catalysts. These combinations are better capable to deal with refractory sulphur species, like poly-aromatic sulphurs [Van der Linde et al].

› Modify reactors internals: reactor internals occupy volume that would otherwise be available for catalyst. A larger volume of catalyst implies that, other things equal, the oil is longer in contact with the catalyst, achieving more desulphurisation. During the last decennia there have been tremendous improvements to reduce the size of reactor internals. Another possibility to improve the HDS process by modifying reactor internals is installing dispersion trays that distribute the oil uniformly on the catalyst surface. This way efficiency is improved.
› Raise start-of-run temperature – shorten cycle run length: together with hydrogen partial pressure a second key variable that determines the level of desulphurisation is the reactor temperature. An increase in temperature lowers the sulphur content, but on the other hand decreases the catalyst run length as well. This is a trade-off, which should be handled with care. In case the HDS units are not capable to produce SFD, it becomes attractive to reduce the catalyst's run length by raising the temperature.
› Add reactor volume: besides modifying reactor internals, reactor volume can be added. For instance a reactor can be added to a HDS or a complete new HDS unit can be built.

The next subparagraph describes which of these best practices are applied by OCR.

2.4.2 <u>Best practices applied by Oil & Co Refinery</u>

Table 2 summarises which of the best practices identified in the previous subparagraph, Oil & Co Refinery (OCR).

Table 2 Best practices applied by OCR

Best practice	Applied by OCR?
Manage feed quality	Partly
Manage dispersion	Yes
Upgrade to new catalyst	Yes
Increase hydrogen partial pressure	Yes
Remove H_2S from recycle gas	Partly
Use combinations of catalysts	No
Modify reactor internals	Yes
Raise start-of-run temperature	No
Add reactor volume	No

Below it is explained to which extent OCR applied the best practices:

› Manage feed quality: considering the crude feed, this practice is not applied because the price of high sulphur crude is lower than that of low sulphur crude. Reason for this is that fewer refineries are capable of processing high sulphur crude. Oil & Co Refinery is capable and can maximise margin by refining high sulphur rather than low sulphur crude. The feed quality of the HDS, on the other hand, is altered. The heavier fraction of light gas oil and the heavy gas oil are no longer diesel components. Hence the pre-blending is discontinued. This way the HDS capacity is unburdened.
› Manage dispersion: the sulphur most difficult to remove from oil is embedded in the refractory sulphur species. The HDS capacity on OCR is not sufficient to remove these species easily and thus producing SFD becomes problematic. The solution chosen by OCR to unburden the HDS's is changing the cutting temperature of the light gas oil fraction, the main component of SFD. The T95-temperature of light gas oil is lowered, eliminating the refractory sulphur species from the light gas oil fraction. This makes deep desulphurisation to sulphur levels below 10 ppm feasible. A consequence of this lowering of the cutting point is that T95 and cloud point are

always within the SFD specifications. A revamp of the CD's is necessary to cut the LGO differently. CD/5 is already revamped; CD/6 is going to be revamped in 2006.

- Upgrade to new catalyst: HDS/1, HDS/2 and HDS/3 all got a next generation catalyst, suitable for SFD production. The supplier of the new catalyst is Cataly, one of Oil & Co's subsidiaries.
- Increase hydrogen partial pressure (H_2pp): although the degrees of freedom for increasing the H_2pp are limited, this variable is raised by adjustments that enable to increase operating pressure in the HDS/3 by a couple of bar. Furthermore the internal hydrogen network of OCR is changed to raise the purity of the hydrogen used in the HDS's. Currently the hydrogen producing plants supply hydrogen to a number of hydrogen demanding plants. The purities of the hydrogen flows produced differ and the allocation of these hydrogen qualities occurs following a certain priority-list. The HDS's is given a higher priority, i.e. the purity of the hydrogen used for desulphurisation is higher.
- Remove H_2S from recycle gas: a very effective way to clean the recycle gas is by using amine scrubbing. Amine adsorbs the H_2S, removing it from the recycle gas flow. HDS/1 and HDS/2 are already equipped with an amine system, called dipa-system [Smit et al]. Dipa stands for di-isopropanol amine. In paragraph 5.1 and Appendix 5 a more extensive explanation on the dipa-system can be found. HDS/3 is not yet equipped with a H_2S removal system, unknown is if in the near future this system will be installed.
- Use combinations of catalysts to handle complex sulphur aromatics: this practice is not applied, because it is a relatively new technology and little experience is available. It might be a good option in the future if further improvements are required.
- Modify reactors internals: during the last maintenance stops the internals of HDS/2 and HDS/3 were adjusted. The number of reactor beds was reduced from 5, including quench inter-bed cooling, to two without inter-bed cooling. During the next catalyst replacement stop the reactor internals of HDS/1 are going to be changed also: 2 reactor beds, no quench. Dispersion trays are already installed in the HDS's; further improvements regarding reactor internals are limited.
- Raise start-of-run temperature – shorten cycle run length: as long as with normal effort the production of SFD is feasible it is neither necessary nor preferred to raise the start-of-run temperature. If, during test runs, it turns out that with the current adjustments OCR is not capable of producing SFD, this may become an option. For the time being the expectation is, though, that this is not necessary.
- Add reactor volume: this is the most expensive option and thus not implemented.

Another OCR practice that is not directly related to any of the best practices is the installation of Quality Measuring Instruments (QMI's) that measure the sulphur content of the HCU gas oil and the HDS effluents.[1] These QMI's are going to provide input to local control systems (see §2.4.4). Also the functioning of the RBL AGO blender, already discussed in § 2.3.2, is altered (see §2.4.5).

Furthermore a connection is made for the HCU gas oil to go from OCR to the Low Olefins plant as feed for the production of low olefins. Currently gas oil desulphurised by HDS/5 is used as LO feed, but in the future TGI gas oil is continuously added to the HDS/5 feed. This makes that gas oil is no longer suitable as LO feed.

2.4.3 <u>Sulphur Free Diesel production</u>

The diesel production is, as mentioned above, going to change significantly. Figure 4 represents the set up of the future diesel production.

[1] At this moment none of the QMI's, and thus none of the HDS SMOC's, are operational.

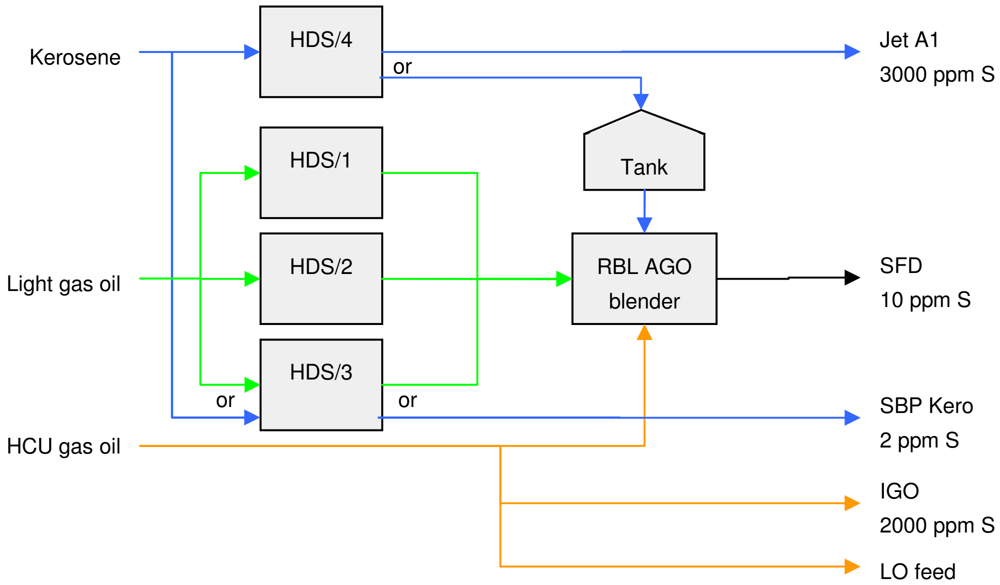

Figure 4 Future diesel production

As mentioned in the previous subparagraph the pre-blending is discontinued. Just as in paragraph §2.3.1, the end product forms the starting point for clarification of the above figure:

- Jet A1: this production is not changed.
- Sulphur Free Diesel: heavy gas oil is no longer a diesel component. Only light gas oil (LGO) is desulphurised by the HDS's. The desulphurisation of kerosene has a 12-day cycle: during 10 days the, by HDS/4, desulphurised Kero (Des-Kero) goes to the Jet A1 pool, the two following days the Kerosene is desulphurised to 7 ppm. This Des-Kero is stored in tanks. After sulphur measurements are performed and static electricity is diverted. If the sulphur content is on target, the stored Des-Kero can be blended in the SFD pool. The sulphur target is currently set on 7 ppm. The quantity of HCU gas oil, that can be blend in the diesel pool, is determined by the sulphur content of this flow. Subparagraph §2.4.5 elaborates more on the RBL AGO blender, where the Des-LGO, Des-Kero and HCU gas oil are blended. In the past the production unit responsible for distilling the diesel components and preparing the HDS feed, RUD, was mainly responsible for the diesel quality as the diesel quality depends directly on the distillate and HDS feed properties and further down the production process there were limited opportunities to alter diesel quality. In the new situation RUD is no longer responsible for blending. Instead part of the responsibility for the diesel quality is transferred to the production unit responsible for the after-blending, RBL. This makes the diesel quality a shared responsibility. RUD is still responsible for the distillates quality, Refinery Treating and Conversion is still responsible for desulphurisation and RBL is responsible for the diesel blending. Chapter 4 and 9 expand more on organisational issues, like the quality responsibility.
- Special Boiling Product (SBP) Kerosene: also in the future HDS/3 is alternately used for the production of diesel and SBP Kero, respectively.
- Low Olefins (LO) feed: depending on the value of HCU gas oil as feed for the Olefins plant, it can be profitable to run down the HCU gas oil to LO. Also in case the HCU gas oil cannot go to the diesel pool, HCU gas oil can be used as LO feed, rather than downgrading it to industrial gas oil.
- Industrial gas oil (IGO): the price of industrial gas oil is normally lower than the prices of all other products. That is the reason why downgrading to the IGO pool is something to be prevented. In case any of the streams (Des-Kero, light gas oil or HCU gas oil) does not meet the sulphur targets and they cannot be run down to

another product pool they should be downgraded to the IGO pool. Kero can, in case the sulphur content is too high and the colour is still on spec, run down to the Jet A1 pool. HCU can be run down to the Low Olefins plant. Unfortunately the production of HCU gas oil is larger than the demand for LO feed. The surplus of HCU gas oil in that case should be downgraded to IGO.

2.4.4 Automated control on the desulphurisation units

All three hydrodesulphurisation units. HDS/1, HDS/2 and HDS/3, are equipped with a Super Multi-Variable Optimising Controller (SMOC). A scheme of this automated control system on the HDS's can be found in Appendix 3. The main idea of the HDS SMOC's is that a sulphur analyser measures the sulphur content in the HDS effluent. SMOC compares the measured value with the target value. Deviations from the target can be corrected by regulating two steering instruments:

- A first instrument is the combustion control: if the sulphur content in the effluent is too high, the SMOC steers the combustion control to increase furnace temperature. This will increase the level of desulphurisation.
- If the temperature has reached its maximum a second instrument is deployed. The feeding is reduced. This increases the time the product spends in the HDS reactor, thus increasing the quantity of sulphur removed. Lowering the throughput is an undesired phenomenon because it implies reduction of diesel revenues. The second instrument should, therefore, only be applied in case of emergency, i.e. if there is a threat the product is going to be off spec.

2.4.5 Automated after blending

For SFD production the quantity of HCU gas oil that can be blended into the diesel pool is constrained by the sulphur content of HCU gas oil. During the HCU catalyst's run length of 4 years, the sulphur content gradually increases. In theory the sulphur content is around 5 ppm[1] after catalyst replacement and rises gradually to approximately 20 ppm after 4 years. As long as the sulphur content of the HCU gas oil is below the 10 ppm, all HCU can be blended in the diesel pool. In case the sulphur content is above the 10 ppm, the quantity of HCU gas oil blended in the diesel pool depends on the sulphur content in the other flows and the underlying economics. Additionally HDS/4 desulphurises kerosene to 7 ppm and depending on the gain[2] of blending the lighter Des-Kero with the diesel, Kero is blended in the SFD pool.
The blending of the Des-Kero, light gas oil and HCU gas oil is done by an automated blending tool, the RBL AGO blender. The RBL AGO blender optimises the blend based on the component properties and the targets set for the blend properties, economics are not included into the RBL AGO optimiser.

2.4.6 Future challenges

The future SFD production raises a couple of challenges:

- Dealing with a lack of experience and data: OCR is going to be (one of) the first that produces SFD out of high sulphur crude with such tight HDS capacity.
- Handling the quality margin and the measurement inaccuracy. To guarantee that the diesel is on spec at the gas station a quality margin is required sufficient to cope with potential contamination after production. Another reason for building in a quality margin is the measurement inaccuracies of the Quality Measurement Instruments (QMI's). The expected inaccuracy is 1.5 ppm, a significant amount compared to the product specification of 10 ppm. In practice this implies that the production target for

[1] Short after the HCU maintenance stop sulphur contents of 4 ppm were measured.
[2] All internal product streams are expressed in tonnages, while the products involved are sold in volumes (cubic metres). It, therefore, can be profitable to add kerosene, to lower the density of the diesel, so that cubic metres sold, and thus revenues, are maximised.

sulphur is 8.5 ppm, further constraining the production process. Uncertain is how great the quality margin should be and if the inaccuracy can be reduced.

› Managing dead times. A dead time is the time between a change in production settings and the desired outcome. The dead time in a HDS is the time between raising the WABT and producing product with the sulphur content corresponding with the new WABT, several hours.

  Des-Kero production shows a different type of dead time. The dead time of blending Des-Kero in the diesel pool is negligible, as it is just a matter of opening valves. The dead time between the production of Des-Kero and the blending, on the other hand, is significant. It costs approximately 2.5 days to fill the two tanks available for Des-Kero; total quantity approximately 10 kiloton. After filling the tanks the Des-Kero should be tested. In total thus the dead time between starting production and being able to blend Des-Kero in the diesel pool is circa 3 days.

› Minimising quality give away. An important term in the refinery process is quality give away. Give away is the degree to which a product property differs from product specifications. Of course this applies only for material that has a too high quality, because products that violate specifications are simply off-spec and should be downgraded to a lesser valuable product, e.g. IGO.[1] Sulphur give away occurs when the sulphur content of diesel is below the 10 ppm specification. Due to the large quality margin it can occur that a product has a sulphur content of 7 ppm, implying that too much effort was put in the desulphurisation (e.g. catalyst deactivation, energy, time). For every product property give away can appear. In fact some give away is almost inevitable as products are always constrained by a property. In winter, for instance diesel is most likely to be cold flow properties constrained.

  One huge potential costs saving can be found in minimising quality give away.

› Maximise margins: the new Oil & Co strategy aims at more upstream and a more profitable downstream. In 2004 Oil & Co made the news a couple of times due to issues around the oil reserves. Oil & Co recognises the need to raise the company's oil reserves and for this reason desires a profit generating downstream to invest in the upstream. For some years now there already exists a programme to make the downstream more profitable, the Global Margin Improvement (GMI) programme. This programme consists of an extensive number of projects to improve performance locally. OCR identified approximately 30 GMI projects.

› Deal adequately with the shared responsibility for the diesel quality and the small margin for compensating disruptions. Cooperation and good communication should predominate, not that production units shirk their responsibility. How can the overall performance, cooperation and communication be assured?

2.5 Opportunity for performance improvement by SFD optimiser

The future production as described in the previous subparagraphs will, as expected, enable Oil & Co Refinery to produce sulphur free diesel. 'As expected', because not all HDS's are tested[2] and thus this capability is not proven. Assuming that OCR will be able to produce sulphur free diesel, this process will be very critical (see previous paragraph). The quality margin becomes significant, the desulphurisation capacity is limited and the margin for compensating disruptions is small. This asks for a coordination of the sulphur free diesel production, which integrates the automated control on the desulphurisation units with the automated after-blending. This initiative is part of the previously mentioned Global Margin Improvement (GMI) programme, which aims to increase refinery margin by 50 dollar cents per barrel, by the year 2007. In the GMI programme this initiative was referred to as the diesel

[1] A nuance should be made. Sometimes it is possible to compensate for a intermediate product that is off spec, by blending it with a product that has give away on the properties concerned.

[2] HDS/1 is tested in February and desulphurised to a level of 7 ppm smoothly. HDS/2 and HDS/3 are planned in the end of February and beginning of March 2005.

site-wide optimiser and the gain of this optimiser was estimated on an additional refinery margin of 0.65 $c/bbl. This equals an annual benefit of approximately $850,000. Basis for this benefit are the minimisation of the quantity HCU gas oil downgraded to industrial gas oil pool and extension of the HDS run lengths by two months each [Jansma]. Prerequisite for achieving these benefits is integrated steering of the SFD production, that includes catalyst lifecycle economics, diesel specifications, component properties, profit and quality margins. The site-wide diesel optimiser, from now on called the SFD optimiser, aims to do so. Figure 5 sketches the main idea of the SFD optimiser; a decision support tool that takes in blend values and properties of the diesel components. Then, taking into account the deactivation costs and SFD specifications, determines the production settings for the Des-Kero production (HDS/4), the desulphurisation of light gas oil (HDS/1/2/3) and the blending (RBL AGO blender).

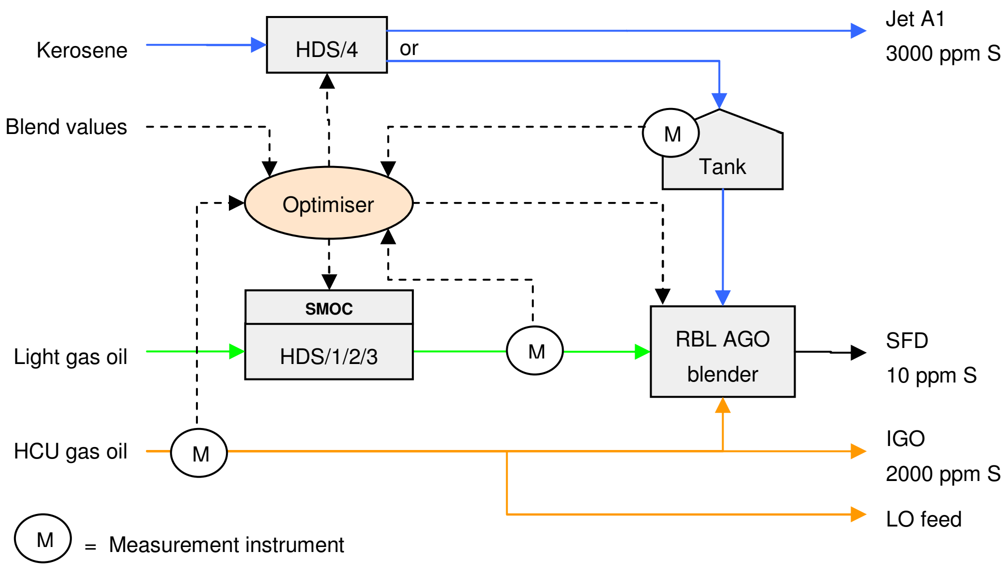

Figure 5 Opportunity for SFD optimiser

This optimiser is important for a couple of reasons. First of all it can optimise the economic performance regarding the diesel production, as both costs of the diesel production, e.g. desulphurisation, and the revenues are included in the decision-making. Secondly the run length can be expanded if the level of desulphurisation on the HDS's is adjusted to the situation, rather than a steady state operation. Thirdly this research can help increasing the comprehension of the sulphur free diesel production, an unknown field for Oil & Co Refinery. These reasons point out the relevance of this research project.
The next Chapter deals with the research set-up, where the basis is constructed for the development of the SFD optimiser.

3 Research outline

The former chapter gave an idea of the current and future diesel production, resulting in the identification of opportunities for improvement. This chapter contains the research outline [Salverda, 2004] in order to analyse and improve the diesel production at OCR. First the project goal is formulated (§3.1), with the project scope (§3.2) Then the research questions that follow from the project goal are identified (§3.3). The last paragraph (§3.4) gives an indication of the expected outcome.

3.1 Project goal

Develop a decision support tool (SFD optimiser) that successfully optimises the sulphur free diesel production. To be successful the decision support tool should be effective and reliable, but also be able to deal with the organisational complexity of the environment.

- The process optimisation consists of an optimisation model that calculates the diesel production settings which result in the highest economic performance, i.e. the highest SFD optimiser margin. This economics performance depends on the total blend value of the diesel components and the costs related to the catalyst lifecycle economics. At all times product specification must be satisfied.
- The organisational review gives insight into the refinery's organisation, considers the consequences of the SFD optimiser for the organisation and provides recommendations on the incorporation of the SFD production.

The terms *SFD optimiser margin, total blend value, catalyst lifecycle economics* and *product specifications* are further explained below:

- SFD optimiser margin: the total blend value of all diesel components minus the deactivation costs (catalyst lifecycle economics).
- Total blend value: decision-making regarding scheduling is based on price estimates. These prices are converted into values of intermediate products which depend on the product's quality. A sulphur poor diesel component, for instance, is more valuable that a similar product which is sulphur rich. Based upon these internally applied values next week's production is determined. If for instance kerosene's value in the SFD blend is higher than of the value of kerosene in the Jet A1 pool, the quantity of Des-Kero in the SFD blend is maximised. The total blend value is the sum of the quantities of all (potential) diesel components times their value.
- Catalyst lifecycle economics: aspects of the catalysts lifecycle economics are run length, deactivation, loss of margin due to replacement stops, catalysts purchase and replacement costs etc. Because the run length of the catalysts used ranges from 1 year (HDS) to 4 years (HCU), the process optimisation should maximise economic performance on the long term.
- Product specifications: in the preceding sulphur free diesel was said to have many specifications (e.g. flash point, density, T95, colour and of course sulphur). These specifications should be satisfied at all times.

3.2 Project scope

The scope of the project is as follows:

- The production of sulphur free diesel (SFD) and its alternative end products (Jet A1, LO feed and industrial gas oil) are considered.
- Mostly the future situation, hence when the sulphur free production is operative, is considered. In case current issues are addressed this is explicitly mentioned.
- There are five main actors, involved in the sulphur free diesel production: the economics and planning department, and the production units responsible for

blending (RBL), production of HCU gas oil (RCP), desulphurisation of kerosene (RUD) and desulphurisation of light gas oil (RTC).

› At the beginning of the second quarter of 2005 a new performance assessment system is introduced, which has subtle differences compared to the old system. This report only considers the situation in which this new system is operative.
› Given the fact that the Hydro Cracking Unit's prime function is not to desulphurise but to denitrify. Therefore the operation of the Hydro Cracker is mainly steered for denitrification purposes. Hence, there are few degrees of freedom to steer the sulphur content in the HCU gas oil. For the optimisation of the sulphur free diesel production the sulphur content in the HCU gas oil is considered given.
› Degrees of freedom for optimisation are the blending quantities and the level of desulphurisation of light gas oil.
› The choice of crude is not a steering variable in the decision support tool; instead the impact of the choice of crude on the diesel production is included as different crude oils result in different properties of the diesel components.
› Future changes in sulphur specifications for other product groups, like the tightening up of the IGO sulphur specification to 1,000 ppm by 2008, are assumed to not affect the price differentiations between the end products involved.
› The line-up of the SFD production is given. This assumption is made because the decision-making procedure for configuration changes is extensive and also the physical implementation of such adjustments takes a long time. Any suggestions for line-up improvement are noted in the recommendations (§10.2).

3.3 Research questions

The main question of this research project is:

What does a decision support tool look like that optimises the sulphur free diesel production, i.e. maximises the SFD optimiser margin, taking into account product specifications and the organisational complexity?

To find the answer to this question seven research questions are formulated:

1. In which setting does the introduction of sulphur free diesel takes place?
    a. What is the reason for the introduction of sulphur free diesel?
    b. What are diesel properties and specifications?
    c. How does the refinery process look like?
    d. How does the refinery organisation look like?
    e. How is diesel currently being produced?
    f. What are the best practices for sulphur free diesel production?
    g. Which best practices are applied by Oil & Co Refinery?
    h. How is the (future) sulphur free diesel production designed?
    i. Which future challenges can be seen?
    j. Do opportunities exist for performance improvement by a decision support tool that optimises the sulphur free diesel production?

2. How can the organisational complexity be described?
    a. What are the main actors involved in the sulphur free diesel production?
    b. What are their tasks and responsibilities?
    c. What are the objectives of the actors involved?
    d. How does decision-making take place?
    e. What are the instruments these actors have at their disposal?
    f. How can the organisational complexity be described?
    g. What are the requirements regarding the decision support tool?

3. How can the technical problem be conceptualised
    a. Which activities are relevant for the sulphur free diesel production?
    b. Which factors are relevant?
    c. What are the dependencies between these factors?

4. What does the decision support tool for optimisation look like?
    a. What is the goal of the model of the optimisation problem?
    b. What are the specifications of the model?
    c. What is the scope of optimisation
    d. Which factors should be included in the model?
    e. How does the optimisation problem look like?
    f. What kind of optimisation problem is it?
    g. Which algorithm is best suited to solve the optimisation problem at hand?
    h. Which software is, given the model specifications, the most suitable?
    i. Does the model pass the verification and validation tests?

5. What are the characteristics of the decision support tool?
    a. Who is going to use the decision support tool?
    b. How should the model be used?
    c. What are the potential gains of the SFD optimiser?
    d. How should the SFD optimiser be implemented?
    e. To what extent does the SFD optimiser meets the tool requirements?
    f. To what extent can the decision support tool be generalised for other refineries or processes?

6. What is the chance of a successful incorporation of the process optimisation in the OCR organisation?
    a. What are the consequences of the SFD optimiser for the organisation?
    b. To what extent can the performance assessment be improved?
    c. What is the chance of successful incorporation of the process optimisation in the OCR organisation?
    d. What are the prerequisites for successful incorporation?

7. What is the research conclusion?
    a. What can be concluded based on the research?
    b. Which further improvements can be made to improve OCR performance?
    c. What are recommendations that derived from the research?

In Appendix 4 the complete research setup, i.e. research questions and research approach is described. Here only is indicated in which chapter a research question is answered:

Question	1	2	3	4a-h	4i	5	6	7
Chapter	2	4	5	6	7	8	9	10

3.4 Expected outcome

Oil & Co Refinery's expectations regarding this project were mainly related to the process optimisation. During the interviews held with OCR staff it became clear that the expected outcome of this research project was an off-line model which calculates the optimal production settings on a weekly basis. But, the student considers also the organisational complexity relevant for a successful incorporation of the process optimisation in the organisation. It is one thing to develop a very optimisation tool, successfully implementing and incorporating it in the organisation is another. Only that way, the realisation of the potential gains of the process optimisation is guaranteed.

4 Survey of organisational complexity

This chapter elaborates on the organisational complexity of Oil & Co Refinery that should be kept in mind during the development of the decision support tool. In paragraph 2.2.3 the Oil & Co Refinery's organisation was discussed briefly. This chapter aims to give the reader a more extensive overview of the main actors, their objectives and the instruments they have to influence the diesel production. Also some theoretical notions are introduced to describe the organisational complexity. This chapter concludes with some requirements for the decision support tool that is going to be the subject of the next four chapters.

4.1 Recapitulation refinery organisation

Figure 6 summons the main actors, their tasks and their responsibilities regarding the sulphur free diesel production, as defined in paragraph 2.2.3:

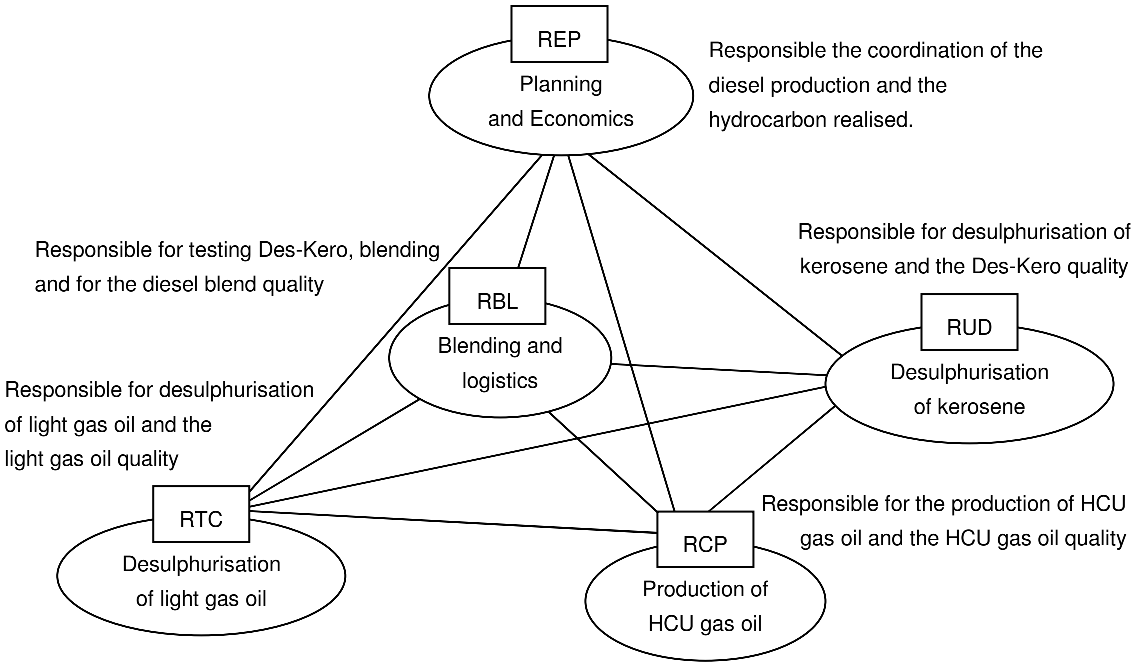

Figure 6 Pyramid of main actors, their tasks and responsibilities regarding the sulphur free diesel production

Later on in this chapter it becomes clear why the network of these actors is presented as a hierarchal pyramid in which the production units form the basis and in which the economics and planning department is on top.

4.2 Actor objectives

This paragraph investigates the objectives of the actors involved. The first subparagraph identified the overall, site-wide objectives. The second subparagraph discusses the delegation of these site-wide objectives to the organisation parts.

4.2.1 <u>Site-wide objective analysis</u>

The method used to structure and analyse the objectives of actors is called objective tree. In an objective tree the principle and main objective of an actor is put on top of the tree. This goal can only be achieved by realising a couple of sub goals. These sub goals are achieved by realised objectives on even a lower and more detailed level, etc. This way a tree of objectives of multiple levels of aggregation is constructed. After the trees of different actors are constructed, the trees can be analysed. Two possibilities for analysis are possible:

› The relations (consistencies and conflicts) between goals in one tree are analysed.

› The relations (consistencies and conflicts) between goals from two or more trees can be analysed.

The first method shows to which extent the objectives of an actor are in balance and harmony, or that an actor has conflicting objectives. For instance, a company aims to maximise profit, thus minimal costs, but also desires a maximal level of safety, which implies investments in maintenance and control. The second method analyses the relationship between actors in terms of goals. Similar goals will stimulate actors to cooperate, while conflicting goals will result in competition between actors.

Below the overall objectives of the refinery are identified. These objectives correspond to a perspective of the refinery management. The constructed objective tree also includes the key performance indicators, introduced in paragraph 2.2.3. These KPI's are represented in the bright yellow boxes.

The refinery's main objective is to maximise the site-wide performance. This can be achieved by maximising performance of both financial (i.e. profit) and non-financial factors (i.e. health, safety and environment). Because the complete tree is too large to present here, it is cut into two branches: the financial branch (profit) and the non-financial branch (health, safety and environment).

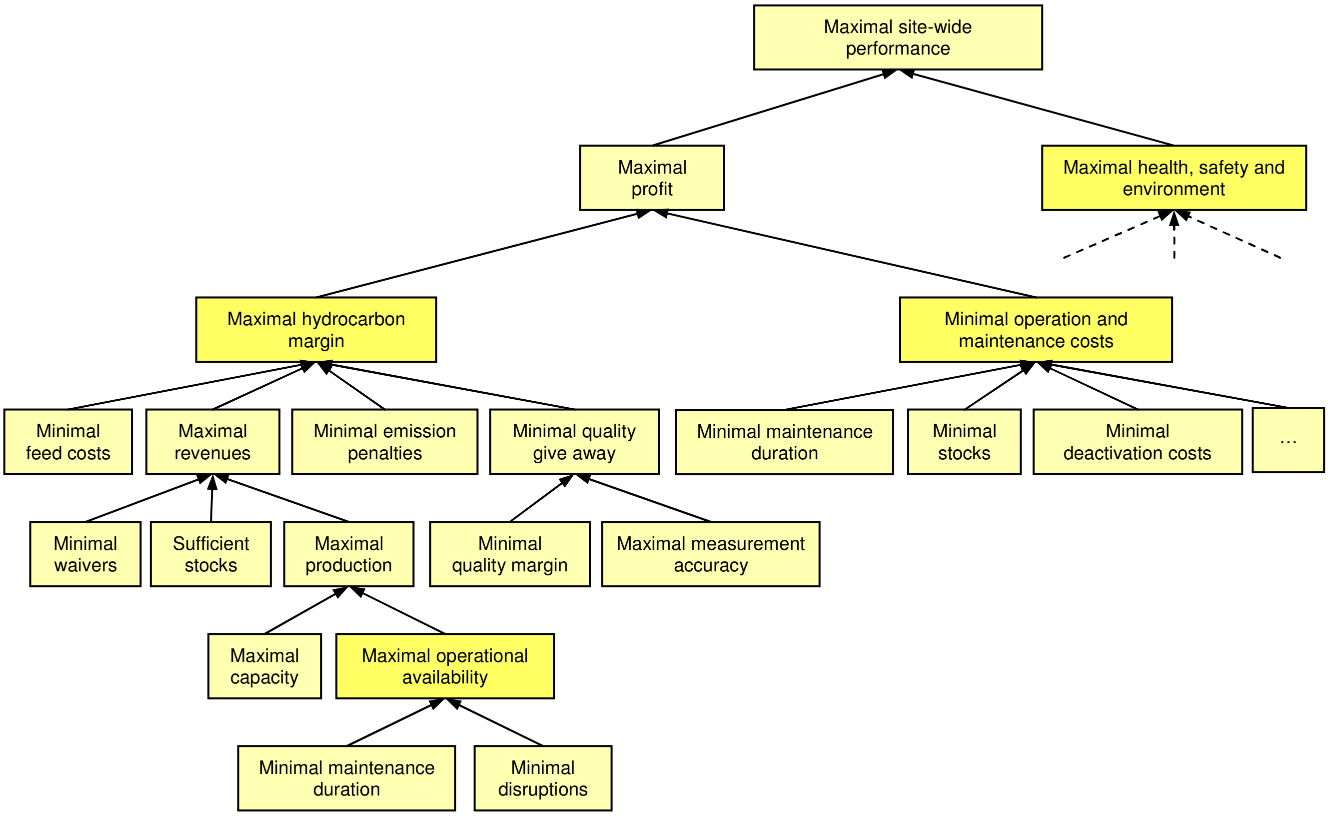

Figure 7 Financial branch of site-wide objective tree

First the financial branch is clarified, see Figure 7: profit can be maximised by optimising the two key performance indicators: hydrocarbon margin and costs of operations and maintenance. Hydrocarbon margin is defined as the revenues minus the feed costs, the penalty on emissions and the quality give away. Revenues depend on the product prices (waivers) and the product quantities (stock plus production). Production is determined by the maximum production capacity and the time that capacity is utilised (operational availability).

The second sub objective of profit, namely operation and maintenance costs, depend on, amongst others, the duration of maintenance, stocks and deactivation costs, as these three factors represent expenditures for operations for the sulphur free diesel production.

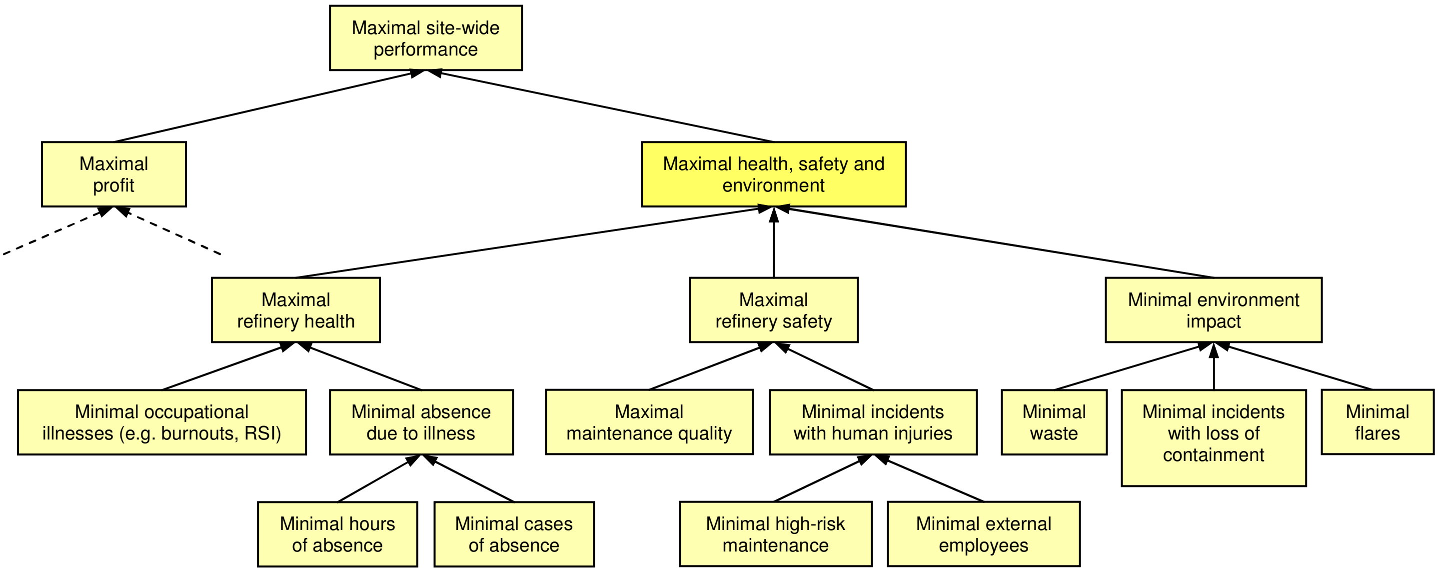

Figure 8 Non-financial branch of site-wide objective tree

The second branch of the refinery performance tree deals with the health, safety and environmental goals, see Figure 8. Health depends on the absence due to illness and the number of occupational illnesses, like RSI and burnouts. Safety depends on the quality of maintenance and the number of incidents with human injuries. This latter factor is closely related to maintenance, in particular the number of high-risk maintenance activities and the number of external workers employed during maintenance stops. In general maintenance implies situations in which personnel works in far from safe conditions, thus with a higher risk of accidents. Imagine the maintenance activities on top of a flare, on platforms, etc. Environment depends on the quantity of waste, flares and loss of containment.

Now some of the most important conflicts in the site-wide objective tree are described:

› Maintenance: safety versus operational availability
  High safety requires maximal maintenance quality, resulting in well-maintained and reliable equipment; and minimal high risk maintenance activities, which minimises the chance of accidents. To minimise the loss of income due to maintenance, the duration of maintenance stops should be minimised in order to maximise operational availability. These objectives are not conflicting directly; a tendency field exists in which maintenance should occur fast, good and safe. Generally speaking the first is improved at the expense of the latter two. This tendency takes place at the level of the production units as they are main responsible for the maintenance of their own equipment. In practice this tendency is dealt with: the stop schedule determines the time frame in which the maintenance takes place; the investments depend on the budget, good preparation maximises safety and the actual execution of the maintenance work determines the quality. When the maintenance stops are adequately planned it's possible to execute maintenance assuring employees' safety, staying within the time frame and budget and assuring the quality of the work done.
› Stocks: revenues versus costs
  To maximise revenues it is important to be able to fulfil all demand and thus have sufficient product available to prevent 'no'-sales. One way to guarantee the capability to fulfil customers' demand is to have sufficient stocks. But this is in conflict with the aim to minimise operational costs, under which storage costs fall. This is a tension the schedulers from REP have to deal with. It's a trade-off between minimal stocks to minimise costs and have sufficient storage capacity to take care of product surpluses (of feed of the faulty unit) in case of upsets, on the one side. And, on the other hand,

have sufficient stocks to prevent no-sales and take care of shortages (of effluent of the faulty unit) in case of upsets.

› Choice of feed is not included in the tree because the impact of this choice is ambiguous; the choice of crude affects a couple of goals in the tree. To reduce feed costs, the cheapest crude oil should be used. For instance heavy and high sulphur crude is cheaper than other crude oils. But, in general, heavier and high sulphur crude is harder to process, thus driving up operational costs. Furthermore it may be expected that cheaper crude oil result in more pollution after refining thus the environment is also affected negatively if feed costs are reduced. In practice crude oil is chosen, by the crude scheduler of REP, that results in the maximal hydrocarbon margin and provides the desired product mix.

› Quality give away: from a revenue perspective the number of waivers (times when product is sold for a low price because it is off spec) should be minimised. To assure the quality of product it can be advisable to build in a quality margin. This quality margin is inherent to a quality give away as the quality is higher than the specification. This is in conflict with another sub goal of maximal profit, namely minimise quality give away to maximise hydrocarbon margin. In practice the production units build in a quality margin to compensate for any disruptions, while for blending the rule of thumb is *target equals specification*. Regarding, for instance, the sulphur free diesel production the target of the sulphur content in the HDS effluent is circa 8.5 ppm, while the target for blending is 10 ppm.

The enumeration of conflicting goals may not be exhaustive; new conflicts may appear if the objective tree is worked out in more detail. It can be concluded that, in practice, often conflicting objectives are resolved. Otherwise conflicts are delegated to actors, who must make trade-off to resolve these conflicts. This is further explained in the next sub paragraph.

4.2.2 Delegation of objectives to organisation parts

To steer the different organisation parts (production units and staff departments) Oil & Co Refinery employs key performance indicators and by doing the refinery management assumes that the KPI's function as incentives that assure realisation of site-wide objectives. There are two seeming imbalances in the division of the key performance indicators and its delegation. Below these imbalances are described and explained. The first seeming imbalance concerns the division of the KPI's over the two branches: the financial branch contains three KPI's, namely hydrocarbon margin, operation and maintenance costs, and operational availability. The non financial branch contains only one KPI, i.e. Health, Safety and Environment. This unbalanced division does not mean a real imbalance for by two reasons. First of all it is necessary to note that this latter KPI (HSE) in fact consists of two performance indicators: the number of accidents with human injuries (Health and Safety) and the number of incidents with loss of containment (Environment). Secondly two of the financial key performance indicators interrelate; operational availability determines (partly) the hydrocarbon margin realised (see Figure 7). Therefore the net division of independent key performance indicators can be considered two-to-two, putting the first (seeming) imbalance into perspective. Besides, looking at the new Oil & Co strategy of *more upstream and more profitable downstream* (§2.4.6) and the Global Margin Improvement Programme (§2.5) the high emphasis for margin can be accounted for.

The second seeming imbalance concerns the delegation of the key performance indicators to the organisation parts, especially regarding the production units and the economics and planning department. Before we continue the seemingly imbalanced delegation, the objective trees of the production units and of the economics and planning department are considered.

To the production units all key performance indicators, except hydrocarbon margin, are delegated. Hydrocarbon margin is not delegated to the production units as it is very difficult to determine the hydrocarbon margin over one unit or even of one production unit. How should revenues be divided over the organisation parts? Which distribution code should be applied?

Such a distribution of hydrocarbon margin is not only hard to achieve and time-consuming, but also prone to strategic behaviour of the organisation parts [de Bruijn, 1999]. Therefore hydrocarbon margin is a KPI that is not specified for the different actors and for which no individual targets are set. For the other KPI's, on the other hand, targets are set. Due to the steering of production units by KPI's and targets, the objectives of the production units are dominated by the realisation of these targets, as indicated in Figure 9.

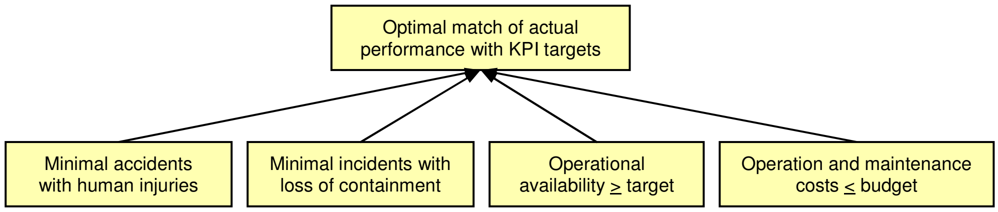

Figure 9 Objective tree of production units

At the end of the year the actual performance of the production units is compared to these targets. Shortcoming performance should be accounted for.

The economics and planning (REP) department aims to maximise its own performance, but as shown in Figure 10, some of the objectives of the economics and planning department concern site-wide performance, e.g. hydrocarbon margin and Health, Safety and Environment.

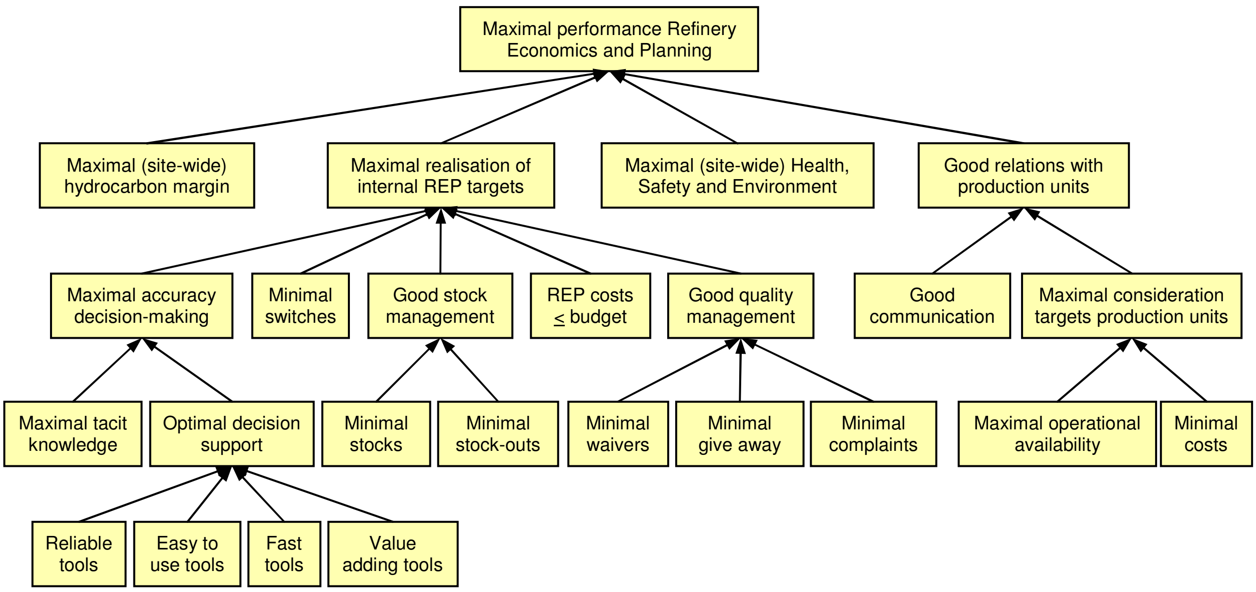

Figure 10 Objective tree of the economics and planning department

Furthermore REP depends on the cooperation of the production units, hence good relations with the production units is a prerequisite for maximising site-wide performance. This requires good communication and taking into account the production unit targets and objectives, especially the KPI's on which REP are not assessed themselves, i.e. operational availability and costs.

Besides the two site-wide goals and the good relationship with production units, REP has also some department objectives; performance indicators on which the economics and planning department is assessed, e.g. accuracy decision-making and predictions, good stock management and good quality management. These latter two concern conflicting site-wide objectives that are delegated to the economics and planning department, from who is expected to make the necessary trade-off. For good stock management it is important that

stock costs are minimised, thus minimal stocks. At the same time stock-outs lead to no-sales and therefore also need to be prevented, thus sufficient stocks. For quality a same kind of trade-off needs to been made. On the one hand minimal waivers (times when off spec product is sold below market value) and the number of (internal and external) complaints about product quality. On the other hand quality give away should be reduced. In practice the rule of thumb, applied by REP, is that the target for end product quality equals the product specification, thus minimising give away. The negative effects are swallowed. Another department objective is maximal accuracy for the decision-making, implying that tacit knowledge within the department should been maximised and that decision-making should be supported by decision support tools where possible. For these decision support tools a number of requirements exist: reliable, easy to use and maintain, fast and value-adding. These requirements should also been taken into consideration for the development of the SFD optimiser.
When the objectives trees of the production units are compared with the tree of the economics and planning department it must be concluded that no direct conflict exist. Rather incentives to cooperate exist as the part of the objectives of the economics and planning department correspond to those of the production units.

Table 3 shows with the ranking of key performance indicators for both production units and the economics and planning department. This ranking corresponds to the previous objective trees.

Table 3 Priorities main actors

Production unit	Economics and Planning department
1. Health, Safety (and Environment)	1. Health, Safety (and Environment)
2. Operational availability	2. Hydrocarbon margin
Costs	3. Operational availability
3. Hydrocarbon margin	4. Costs

For both actor groups health and safety are top priority; no trade-offs are made with human injuries. The other priorities, on the other hand, differ and clearly show the second imbalance regarding the key performance indicators. The production units attach more importance to operational availability and costs, while the economics and planning department's priority is hydrocarbon margin. It is assumed that the net effect of this imbalance leads up to a balance in which the overall performance is assured. The objective tree of the economics and planning department shows that they monitor and guard this site-wide performance.
At the end of 2004 a review was executed that addressed the same (second) imbalance. To create more balance between the four key performance indicators, this review proposed to (partly) delegate hydrocarbon margin to the production units. At this moment this option is looked at. In chapter 9 an alternative option is sought to safeguard the site-wide balance between the four key performance indicators.

Here the most relevant conclusions from this paragraph are mentioned:
- Conflicting site-wide objectives exist, but in practice they are dealt with adequately.
- Production units and staff departments are steered through key performance indicators, to assure that site-wide performance is optimised.
- Main goal of production units is to achieve their targets. Production units are mainly assessed on health, safety and environment, operational availability and costs.
- The economics and planning department is mainly appraised on hydrocarbon margin and its task is to assure the balance in the site-wide performance.

› A decision support tool mastered by the economics and planning department should be reliable, easy to use and maintain, fast and value-adding.

4.3 Decision-making process for the sulphur free diesel production

This paragraph intends to give the reader understanding of the decision-making process regarding the sulphur free diesel production.

4.3.1 Normal decision-making for the weekly schedule

This subparagraph describes the current decision-making for operation that is also applied for the future sulphur free diesel production. Decisions for operations are taken by the economics and planning department based on external (e.g. prices and demand) and internal (e.g. unit upsets, maintenance activities) conditions. The subject of decision-making varies from long term planning (e.g. stops scheduling for next year) to scheduling of next week's production (e.g. choice of crude, throughputs of units, production composition). Here we focus on the decision-making for the short term: the diesel production is determined on a weekly basis. Long term issues, like catalyst deactivation are not included in this decision-making. Overall refinery performance could be improved by decision making that includes such long term effects.

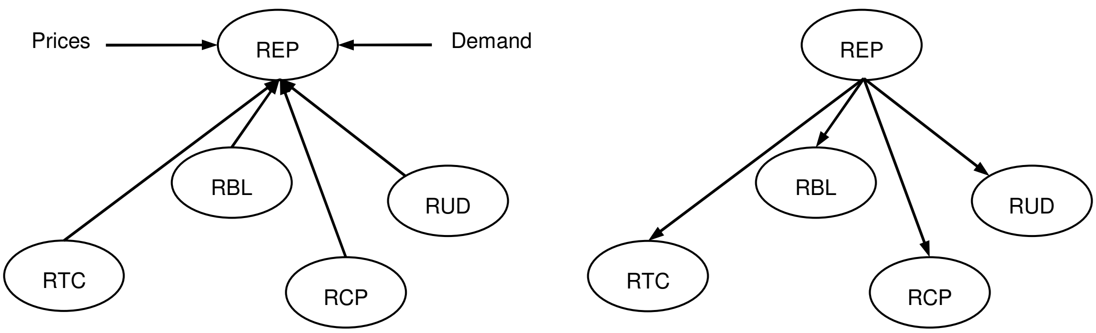

Figure 11 Decision-making process for next week's production

The weekly decision-making process consists of two phases (see Figure 11):

1. First phase is data gathering by the economics and planning department, REP. New data about prices and demand is obtained. During the day-to-day operations REP is kept up-to-date about any irregularities by the production units. Every day at 4 PM the production units and the economics and planning department meet to compare the actual progress to the week schedule. Hence, in practice, REP is well-informed about the operational conditions when next week's production is determined. A linear programming (LP) tool is used to calculate the expected properties of all internal product streams, like those of the HCU gas oil, the kerosene and the light gas oil. Also it estimates the blend value of the different product streams. This LP tool calculates, for instance, the value of kerosene in the Jet A1 pool and the alternative value of kerosene in the diesel pool. Based on the blend values and properties of the internal product flows, product specifications, and operational conditions the LP tool estimates the optimal production settings for the whole refinery. Based upon the tool's outcome the next week's production is determined. These production settings are very generic, e.g. *HDS effluent maximal 10 ppm*. Hence the LP tool is a decision support tool. It is important to note, however, that this tool does not take into account operation costs. Thus, referring to Figure 7, this tool optimises the hydrocarbon margin rather than the profit. The site-wide performance can be improved by including the operation costs in the decision-making. Projecting this conclusion to the sulphur free diesel production, the deactivation costs, i.e. the main operation costs of

the SFD production, should be included in the decision-making. Again, the importance of an overall process optimisation is pointed out.

2. When next week's production settings are formulated, the economics and planning department communicates these settings to the production units. The production settings indicate the desired production, e.g. sulphur level in HDS effluent. The production units are responsible for realising the desired production. In case the production settings are not feasible, the production unit should consult the economics and planning department and together they find a solution.

The scheduling week runs from Thursday till Thursdays. During that week production units aim to operate according to schedule. The production units enjoy a great deal of autonomy, as they decide on how the production settings are realised, how to spend their budget etc. If all goes according to plan the communication, coordination or cooperation between actors is at a normal rate.

4.3.2 Upsets

Often[1] unexpected events occur, varying from small disruptions to major upsets, which distort the week schedule. In case of a major upset the actors involved should react quickly and adequately. A good example of such a major upset is a malfunction in the hydrogen generation plant, which provides hydrogen for the hydro cracking unit (HCU). Regarding the reaction to such an upset a clear separation must been made by the technical problem (the failure in a plant) and the economic consequences (the loss of income due to the upset). The production unit responsible for the faulty unit, RUD, is entrusted with the solving of the technical problem; simultaneously REP tells to RCP to reduce the throughput of the HCU and searches a way to minimise the loss of income. Schedulers and economists search for solutions; because of the upset the feed of the faulty unit needs to be processed or stored elsewhere, the demand for the effluent of the unit needs to be delivered elsewhere etc. These practical issues are solved by REP with consults the production units for possible solution. Often Blending and Logistics (RBL) can temporarily reduce the loss of income by storing the faulty unit's feed, so that it can be processed after the unit is repaired. If the technical problem is solved, i.e. the hydrogen generation plant is repaired, operations can return to normal conditions. The communication during this problem solving process corresponds with Figure 12.

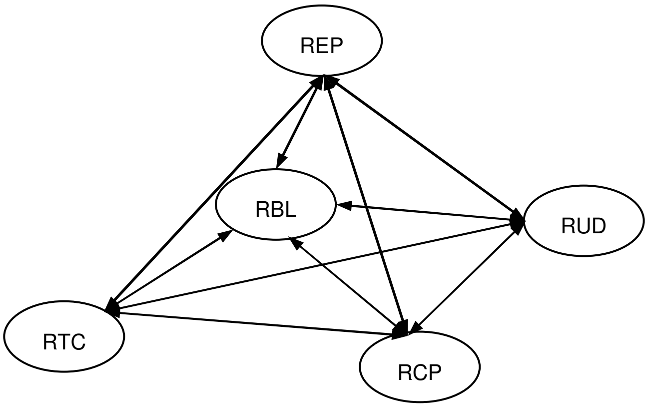

Figure 12 Communication in case of upsets

Depending on the location and nature of the upset some actors play a bigger role in the trouble-shooting process than others. Regarding the sulphur free diesel production upsets can occur in any of the three diesel component streams:

› The Des-Kero is not on spec: there are two ways to discover that the Des-Kero is off spec. The production unit responsible for the desulphurisation of kerosene, RUD, discovers the distortion. Or the production unit responsible for storing and testing the kerosene, RBL, can detect it. In both cases RUD treats the source of the distortion and the economics and planning department should be informed, so that they can search for a way to minimise the damage, i.e. minimise the loss of margin. REP should be informed because they have the overview of the whole refinery. In case a

[1] Especially during start-ups and shutdowns, e.g for maintenance purposes, there is a bigger chance that plants have upsets. The frequency of upsets on the refinery varies from once a couple of weeks during steady state operations to a couple in one week before and after (maintenance) stops.

production unit cannot minimise the damage itself, REP can search for solutions elsewhere. Regarding the sulphur free diesel production, for instance, kerosene with too much sulphur can be compensated by deeper desulphurisation of light gas oil. REP can coordinate this kind of inter-actor problem solving.

› Also the second stream, the light gas oil desulphurised by HDS/1/2/3, can experience irregularities. The sulphur in the HDS effluent, for instance, can rise due to several technical problems, like furnace trip, pressure drops etc. In case one or more of the effluents of HDS/1, HDS/2 and HDS/3 are too high in sulphur, RTC should inform REP and if the increase in sulphur of the affected stream cannot be compensated by other streams, e.g. other HDS effluent or HCU gas oil, RTC starts circulating the HDS feed. Circulating feed means that the effluent of the HDS is recycled as HDS feed. Hence circulating implies that no light gas oil is desulphurised and thus the light gas oil coming from the crude distillers cannot be processed.
› Also the third stream, the HCU gas oil can experience upsets caused by problems in the HCU itself or a disruption in the hydrogen supply from the hydrogen generating plant. A drop in the hydrogen supply implies that the HCU should stop operations or lower the throughput. In case of an upset the production unit responsible for the HCU, RCP, should inform REP. REP considers the options and chooses the solution that minimises the loss of margin.

In all three upset situation the economics and planning department, REP, plays a central role in the coordination of the problem solving to minimise site-wide loss of margin.

So far the following can be concluded. The production units, and the economics and planning department are mutually dependent, as they depend on each other for goal realisation. In normal operations the planning department decides on next week's schedule in such a way that hydrocarbon margin is optimised. For this decision-making REP depends on the production units for knowledge sharing. As REP has no formal hierarchal power over the production units they rely on the production units for the realisation of the week schedule. This dependency enlarges the level of autonomy of the production units as they are responsible for a unique part of the refinery. The production units act in such a way that their targets are satisfied. In case of upsets the production unit responsible for the faulty unit solves the technical problem, but depends on REP for the minimisation of the loss of income. As REP has the overview over the refinery they are most equipped to safeguard site-wide performance. Hence a dynamics of power exists: in normal operations production units prevail, while in case of upsets they require the interference of the economics and planning department.
Referring to the discussion about conflicting actor objectives (paragraph 4.2) it should be noted that the number of conflicts is limited.

4.4 Actors' steering instruments

In the previous paragraph some of the steering instruments of the main actors were mentioned. Table gives an overview of instruments to influence the sulphur free diesel production.

Table 4 Instruments of main actors

Actor	Steering instruments
RTC	Level of desulphurisation of light gas oil (temperature or throughput) Frequency of changing HDS catalysts
RUD	Level of desulphurisation of kerosene (temperature or throughput) Frequency of changing HDS catalyst Production of Des-Kero
RCP	Frequency of changing HCU catalyst
RBL	Blending Logistics
REP	Production settings Long term planning

The production unit responsible for the desulphurisation of light gas oil, RTC, can influence the level of desulphurisation by changing the temperature and/or throughput of the HDS's. This is a short term instrument which has an impact on the deactivation costs and thus on the KPI costs. RTC can also steer on the long term, by the scheduling of catalyst replacement stops, which affects the operational availability of the HDS plants. If for instance there is a structural need of deep desulphurisation, it may be advisable to increase the capability of desulphurisation by replacing the catalysts more often.
The production unit responsible for the desulphurisation of kerosene, RUD, can influence the not only the level of desulphurisation and the frequency of catalyst replacement stops, but also the quantity of Des-Kero produced. HDS/4 is utilised for the production of Des-Kero as well as Jet A1. The division of utilisation for both products can be changed.
The production unit responsible for the production of HCU gas oil, RCP, can influence the desulphurisation in the HCU by changing the HCU catalyst more often, which affects the operational availability of the Hydro Cracking Unit negatively.
The production unit responsible for the blending of the diesel components, RBL, can influence the diesel production by logistics. RBL can send product streams to several destinations. If light gas oil, for instance is not desulphurised enough, it can be downgraded to industrial gas oil, or it can be stored in a tank and be later be adulterated with sulphur poor components to prevent downgrading. Also the blending can be influenced by RBL.
The refinery economics and planning department, REP, has a wide range of steering instruments, as it can alter operations by formulating new production settings. This short term steering mainly influences operation costs and hydrocarbon margin. Also long term scheduling (e.g. stop schedule) is coordinated by REP. The decisions that REP takes regarding the long run mainly affects the operational availability and the maintenance costs.

4.5 Cultural differences within Oil & Co Refinery

Although Oil & Co Refinery (OCR) is one organisation, it can be seen as a complex of cultures. These cultural differences increase the complexity of the organisation, described in the previous paragraphs. There are several cultural dimensions that can be applied to the OCR organisation [Mintzberg, 1983; Morgan, 1986; Von Meier, 1999]:

› Nature of department: the distinction between staff departments and line departments (production units) was already made in §2.2.3 and has great influence on the way departments look at processes.
› Structure: the refinery's structure can, in terms of Mintzberg [1983] be seen as a mixture of a professional bureaucracy and a division structure. A professional

bureaucracy, as the level of specialism is high and a lot of power and knowledge is in hands of the operators. A division structure, as operations is spread over five production units and every production unit is a quasi-autonomous unit with own objectives. In terms of de Bruijn [1999] the refinery can also be looked at as a professional network, in which the professionalism is a great source of power. A network because although the production units have a high level of autonomy, they depend on the economics and planning department and each other to perform well. Both theories are utilised for the analysis in paragraph 9.2.

› Formal organisation: the economics and planning department, as shown in §4.2, is more focused on hydrocarbon margin, while production units are more focused on operational availability and costs. To maximise the overall performance both focuses should be integrated. This is thus a requirement for process optimisation. Another aspect of the formal organisation is that REP does not have formal hierarchal power over the autonomous production units. Another reason why the combination of both actor perspectives increases the chance of success of the decision support tool.
› Occupation: Von Meier [1999] identifies ‘operator’-cultures and ‘engineer’-cultures. This distinction applies also for OCR: there is a clear difference between personnel concerned with keeping the system working in real-time (operators) and personnel who’s work is more remote from the field (engineers and economists). These occupational differences occur also within actors and link to the structural implications introduced by Mintzberg [1983].
› Topography: OCR is one of The Netherlands’ largest industrial complexes, employing about 1,500 OCR personnel. The OCR site is 3.5 km from the West side till the East side and from North to South is 2.2 km. The different actors are situated on different locations. The staff departments, for instance, are all centralised in the central office on the mid of the South side of the site. The four production units involved are situated on the refinery site. Mostly a production unit is centralised in a certain area of the site, except Oil Movements, which is spread out. These physical distances may contribute to cultural differences.

These cultural differences result in different perspectives on process optimisation and the introduction of a decision support tool for the sulphur free diesel production. In chapter 9 another source of subcultures is addressed, namely bureau politics.

4.6 Requirements for the decision support tool

The analyses in this chapter lead up to a number of requirements for the decision support tool in order to be successful:

› The tool should combine the perspective of the production units (focus on operation costs and operational availability) with the perspective of the economics and planning department (focus on hydrocarbon margin). This enriches the decision-making and results in maximisation of the site-wide performance. The inclusion of operation costs in the decision-making will contribute to the relationship between the production units, and the economics and planning department.
› The time horizon of the tool should correspond to the time scale of the decision-making process for production, i.e. a week.
› Given the central role and the overview of the economics and planning department, the tool is mastered and used by this actor.
› The tool must support the economics and planning department adequately. Hence the tool should provide the information necessary for decision-making, be easy to use and maintain, fast, reliable and value-adding (see Figure 10).

The next four chapters deal with the reduction of the technical complexity, the decision support tool and its outcome. In chapter 9 the organisational review is continued, with regard to the impact of the decision support tool for the organisation and the chance of successful incorporation.

5 Conceptualisation technical problem

To reduce the complexity of the technical problem and determine the main factors in the system, the problem is conceptualised using several modelling techniques. The conceptual modelling and the conclusions that can be drawn from the models are described in this chapter. Firstly, an activity-based analysis is done for the refining process and the sulphur free diesel production in particular (§5.1). Then the relevant factors for optimisation are identified and their mutual dependencies are determined (§5.2).

5.1 Activity-based analysis

Before the process can be conceptualised a thorough understanding of the refinery process is required. A structured method to analyse the refining process and its activity is the IDEF0 methodology. The IDEF0 method was derived from the Structured Analysis and Design Technique, a standard to model the decisions, actions, and activities of an organization or system [Marca, 1987; www.idef.com; www.kbsi.com].

The IDEF0 philosophy is that for a complete process the input, outputs, controls and mechanisms are identified. Inputs (e.g. crude oil) are transformed into outputs (e.g. diesel) using mechanisms (e.g. desulphurisation unit) and steered by controls (e.g. product specifications). After the whole process is defined it can be split up into activities, in case of the refining process crude oil is distilled, desulphurised etc. The activities most relevant for the problem at hand can be divided into sub activities etc.

The following IDEF0 diagrams are made:

- A-0: diesel production process (highest level of aggregation)
- A0: activities of this process
- A4: desulphurisation of light gas oil
- A45: separation of components in the HDS effluent
- A46: sulphur removal from the recycle gas

These five IDEF0 diagrams are enclosed in Appendix 5.

The choice for which activities are analysed in more detail is made on the basis of the activity's relevance, divisibility, uniqueness and manageability. The desulphurisation of light gas oil, for instance, is central in this research and thus studied in depth. Blending does not consist of sub activities and desulphurisation of kerosene is similar to the desulphurisation of light gas oil, and for that reason not explored in depth. The primary distilling in the crude distillers has great impact on the diesel production, but there are in this project few instruments to influence this activity.

It could be concluded, that the IDEF0 methodology builds a good understanding of the production of diesel and relevant issues, which forms a good basis for further analyses.

5.2 Relevant factors and their dependencies

When the production process is understood the factors relevant for the diesel production can be identified. A systematic method for the identification of factors is the List Extension Method (LEM) introduced by Coyle [1996]. The identification of relevant factors was verified by OCR documents, literature and interviews with OCR personnel (e.g. HDS technologist, RBL technologist, economists, schedulers). After defining the relevant factors, the dependencies between these factors are determined using causal relation diagrams (CRD). In causal diagrams the factors are represented in ellipses. Arrows between factors correspond to dependencies. The sign ('+' or '-') indicates the nature of the relation. For instance, in case a positive (+) arrow points from 'revenues' to 'profit' it should be read as follows. If the revenues (source factor) increase, the profit (destination factor) also increases (because of the positive relation). In case of a negative (-) relation, e.g. costs and profit, the profit decreases as the costs increase.

Five causal relation diagrams are made, which can be found in Appendix 6:

- Desulphurisation: central are the sulphur content of the product and the factors that influence the desulphurisation.
- Blending: the way properties and quantities of HCU gas oil, light gas oil and Des-Kero influence the properties of the end product.
- Economics: the financial side of the refinery with some focus on the desulphurisation.
- SFD optimiser margin: the factors influencing the SFD optimiser margin, the central factor in the project goal.
- Quality give away: the method to express give away in monetary units.

The List Extension Method identified all main factors, the Causal Relation Diagrams showed the dependencies between these factors. It can be concluded that the main factors for the optimisation are:

- Technical factors:
  - Properties of diesel components (i.e. sulphur, density, flash point)
  - Product specifications
  - Desired level of desulphurisation
  - HDS settings (reactor temperature, purity hydrogen, operating pressure, throughputs, feed choice)
  - Quality margins for sulphur content, density and flash point
  - Blending quantities
  - Deactivation of HDS catalysts
  - Run lengths HDS catalysts
- Economic factors
  - SFD optimiser margin
  - Total blend value of diesel components
  - Deactivation costs
  - Replacement costs
  - Loss of income
  - Blend values of diesel components
  - Quality give away (sulphur, density, flash point)
  - Price differential sulphur free diesel and high sulphur components

These factors form the basis for the specification of the model for the process optimisation in the next Chapter.

6 Model specification

In the preceding chapter the knowledge of the technical system was conceptualised in several modelling techniques to enlarge the system comprehension. This chapter deals with the development of the process optimisation of the SFD production, the optimisation model. The first paragraph, §6.1, outlines the model goal and characteristics. The second paragraph defines the optimisation model (§6.2). The nature and size of the optimisation model are described in the third (§6.3) and fourth (§6.4) paragraph respectively. The last two paragraphs elaborate on the optimisation algorithms best suited (§6.5) and the applicable software tools (§6.6).

6.1 Model purpose and specification

The situation sketch, the research approach and the problem conceptualisation form the starting point for the model specification. Hence, during the formulation of the optimisation model attention should be paid to the following aspects [Enserink, 2001]:

- Model goal
- Model requirements
- Level of aggregation
- Model definition
- Time horizon and transition paths
- Desired insights

These aspects are explained in the following sub paragraphs.

Model goal

The main goal of the optimisation model is to support the decision-making concerning the diesel production by calculating the solution that maximises the economic performance (SFD optimiser margin) that is related to the scope of this project; i.e. the total blend value of diesel components minus the costs related to the desulphurisation of light gas oil. Degrees of freedom for this optimisation are the quantities of components sent to product pools and the level of desulphurisation in the HDS's. Requirement is that at all times product specifications are satisfied.

Model requirements

Before construction of the model functional and non-functional requirements are stated [Verbraeck, 1999]. Functional requirements are things a model *has to do*. Non-functional requirements are qualities a system *has to have*, which can be used as criteria to evaluate the optimisation model. In chapter 4 it was concluded that the user of the decision support tool is going to be the economics and planning department and that they require the tool to be, at least: functional (i.e. provide the information necessary for decision-making); easy to use and maintain; fast; reliable and value-adding. The following model requirements are considered:

Functional requirements:

- Functionality: calculate the optimal production settings (blending quantities and desired levels of desulphurisation). The optimal solution results in the highest SFD optimiser margin given the current model input.
- Reliability: the experts involved in the sulphur free diesel production should have confidence in the SFD optimiser and its outcome.

Non-functional requirements:

- User-friendliness: when developing a decision support tool the user should be central. Ease of usage, friendliness of interface, usefulness of presentation, ease of maintenance and time expenditure of use are important factors that are critical for user-friendliness.

- Feasibility: the construction of the decision support tool itself, its implementation and outcome (i.e. production settings) should be technically feasible.
- Added value: the net gain realised by the SFD optimiser. Also non-monetary benefits of the model should be considered.
- Robustness: usefulness of decision support tool in case no input data is available and the life span of the tool.

In chapter 8 these requirements will be used to evaluate the performance of the SFD optimiser.

Level of aggregation

The model has a high level of aggregation, as the overall OCR performance needs to be optimised, satisfying the cost-focus of the production units and the margin-focus of economics and planning department. Extremely detailed information is beyond the aim of this project and process optimisation.

Model scope

The model scope is determined by which factors are included in the model as model variables and which factors are not included. Starting point is the conclusion of the Causal relation diagrams (see §5.2 and Appendix 6).

The factors that *are* included are:

- Properties of diesel components (i.e. sulphur content, density and flash point)
- Product specifications (i.e. sulphur content, density and flash point)
- Desired level of desulphurisation on HDS/1/2/3
- Quality margins for sulphur content, density and flash point
- Blending quantities
- Run lengths HDS catalysts
- SFD optimiser margin: total blend value minus deactivation costs
- Total blend value of diesel components
- Deactivation costs HDS/1/2/3: replacement costs plus loss of income
- Blend values of diesel components (kerosene, light gas oil and HCU gas oil)

Below the reasoning for excluding the other factors is discussed:

- Deactivation: is not included in the model directly. There is already a model in place that predicts the HDS catalyst run length. This model, mastered by the HDS technologist, extrapolates the previous degradation to estimate the remaining run length. The outcome of this model, the estimates for run lengths, can be applied in the model. Unfortunately the extrapolation can only be done if a reasonable amount of data is available. Given the fact that the refinery not yet has experience with the production of sulphur free diesel, these data is not available yet. For the time being the run lengths estimated by the catalyst supplier are applied. Appendix 7 shows the relation between the level of desulphurisation and the HDS catalyst run length. When the extrapolation outcomes become available both run length estimates can be compared. I instead of including deactivation itself in the model, the results of deactivation, i.e. catalyst run lengths, are included.

- HDS settings: the economics and planning department, master of the decision support tool, determines the desired properties of the HDS effluent and communicates these to the production unit responsible for desulphurisation of light gas oil, RTC. The knowledge and responsibility for operating the HDS's and realising those properties, is present at the production unit RTC. Hence the decision how to realise these properties is left to RTC, and the economics and planning department does not define the practical HDS settings (e.g. reactor temperature). To respect this operational freedom the decision support tool should indicate the desired HDS effluent properties, rather than the operational settings.

› Financial / economic aspects are reduced to the factors relevant for the optimisation of diesel production. Thus SFD optimiser margin, (total) blend values, deactivation costs, replacement costs, loss of income and the price differential between sulphur free diesel and high sulphur components are included in the optimisation.

› Quality give away: given the scope of desulphurisation of kerosene, desulphurisation of light gas oil and blending these two streams with HCU gas oil, the opportunities to manage quality give away focus mostly on the three constraining properties for blending: sulphur content, flash point and density. The sulphur give away is already included in the model as deactivation costs are included in the optimisation. The give away on the other two properties, on the other hand, are not included. But expected is that in most situations the optimisation model will converge to a solution in which the quality give away of two properties (sulphur and another property) is minimised. Reason for this assumption is that if the SFD blend is sulphur constrained but not constrained on density and flash point, still kerosene can be blended in the SFD pool. Thus automatically the point is reached where either density or flash point become constraining. It is unlikely that a situation exists in which a product is constraining on all its properties, thus a situation in which diesel is constraining on two properties is the highest achievable.

› The distilling of crude and the choice of crude, see also §3.2, are not taken into consideration directly. The impact of a different kind of crude or a different way of distilling affects the properties of the diesel components and therefore is indirectly included.

Time horizon

To define the time horizon of the optimisation model the frequency with which the input should be updated, is considered. Market prices change continuously, but the refinery applies estimates on a weekly basis. Additionally REP communicates on a weekly basis the production settings to the production units. Also the properties of products for the coming week are estimated on a weekly basis. Given the fact that on a weekly basis new data is generated for most of the factors previously identified, the time horizon of the model is a week.

Desired output

The model should provide the optimal solution for next week's SFD production. The solution, the advised production settings, consists of blending quantities and HDS desulphurisation depths. It should be transparent how the advised solution is formed and the user should be able to convert the optimal solution into a feasible one.

6.2 Optimisation problem

This paragraph contains the formulation of the optimisation model; the objective function, the decision variables and their constraints, and the system model and its constraints [Lambert, 1985; Rijnsdorp, 1991].

Objective function

The objective function is formulated as a single criterion, described as a function of decision variables. In this optimisation problem there are two types of decision variables: desulphurisation depths x and quantities q.

$$\max M_{SFD} : f(q_i, x_j) = \sum_{i=1}^{5} (p_i * q_i) - \sum_{j=1}^{3} \left(\frac{C_j}{RL_j(x_j)} \right) + R_{LGO}$$

M_{SFD} SFD optimiser margin (thousands of US dollar per week = k$/w)
p_i value of product stream i (US dollar per ton = $/ton)
C_j deactivation costs, i.e. replacement costs plus loss of income, for a change of the catalyst in HDS/j (k$)
$RL_j(x_j)$ run length of the HDS/j catalyst, if the coming week the desulphurisation depth on that HDS is going to be x ppm (weeks)
R_{LGO} Revenues of the light gas oil (LGO) stream (k$/w)

Decision variables

Eight decision variables are identified:
q_1 quantity of Kero to Jet A1 pool (kt/w)
q_2 quantity of Des-Kero to SFD pool (kt/w)
q_3 quantity of HCU gas oil to SFD pool (kt/w)
q_4 quantity of HCU gas oil to LO feed (kt/w)
q_5 quantity of HCU gas oil to IGO pool (kt/w)
x_1 desulphurisation depth on HDS/1 (sulphur parts per million = ppm S)
x_2 desulphurisation depth on HDS/2 (ppm S)
x_3 desulphurisation depth on HDS/3 (ppm S)

Constraints on decision variables

The decision variables are constrained by upper and / or lower limits:

$6 \leq x_1 \leq 10$, as the activity of a HDS catalyst changes during its lifecycle, the model user can alter these limits.
$6 \leq x_2 \leq 10$, as the activity of a HDS catalyst changes during its lifecycle, the model user can alter these limits.
$6 \leq x_3 \leq 10$, as the activity of a HDS catalyst changes during its lifecycle, the model user can alter these limits.

$0 \leq q_1$

$0 \leq q_2$

$0 \leq q_3$

$0 \leq q_4 \leq \max$, this upper limit is the maximum demand for LO feed. The model user can alter this limit.

$0 \leq q_5$

$q_1 + q_2 = \max$, the model user can alter this quantity.

$q_3 + q_4 + q_5 = \max$, the model user can alter this quantity.

System model

The model consists also of a number of internal equations concerning blending rules and deactivation costs. These equations are described below:

The sulphur content of the diesel blend is the weighted average of the sulphur content of its components:

$$S_{SFD} = \frac{S_2 * q_2 + S_3 * q_3 + S_{LGO} * q_{LGO}}{q_2 + q_3 + q_{LGO}}$$

S_{SFD} sulphur content of the SFD blend (ppm)
S sulphur content of product flow (ppm)
q quantity of product blended into the diesel pool (kt/w)
Possible component products of the diesel pool are: Des-Kero (q_2), Des-LGO from HDS's (q_{LGO}) and HCU gas oil (q_3). The quantity of Des-LGO is not a decision variable because the complete supply of this stream should be used for diesel production unless the Des-LGO is off spec. In the latter case it is downgraded to the IGO pool. As the downgrading only occurs in case of upsets of the HDS's, and the frequency and time of upsets is unforeseeable, it is assumed that the complete quantity of Des-LGO produced is blended in the diesel pool.

The density of the diesel blend is the weighted average of the densities of its components:

$$\rho_{SFD} = \frac{\rho_2 * q_2 + \rho_3 * q_3 + \rho_{LGO} * q_{LGO}}{q_2 + q_3 + q_{LGO}}$$

ρ_{SFD} density of the SFD blend (kg/m^3)
ρ density of product stream (kg/m^3)
q quantity of product blended into the diesel pool (kt/w)

The flash point of the diesel blend is not as easy to determine as sulphur content and density. To calculate the flash point (FP) of the SFD blend the flash point of its components should be converted to flash point indices (FPI). The weighted average FPI needs to be reconverted to the flash point of diesel:[1]

$$FP_{SFD} = \frac{2414}{\log\left(\frac{FPI_2 * q_2 + FPI_3 * q_3 + FPI_{LGO} * q_{LGO}}{q_2 + q_3 + q_{LGO}}\right) + 6{,}1188} - 230{,}5556$$

Where the flash point indexes of the individual product streams are calculated by the formula:

$$FPI_i = 10^{-6{,}1188 + \frac{2414}{FP_i + 230{,}5556}}$$

FP flash point (^{o}C)
FPI_{SFD} flash point index of the SFD blend
FPI flash point index of product stream
q quantity of product blended into the diesel pool (kt/w)

The objective function includes the deactivation costs C_j. These deactivation costs are determined by the costs of a HDS catalyst replacement stop and the loss of income during that stop:

$$C_j = t_{stop,j} * \varphi_j * \Delta p_{SFD-HSC} + C_{replacement,j}$$

[1] Blendrule provided by the RBL technologist.

C_j	deactivation costs of HDS/j (k$)
t_{stop}	duration of catalyst replacement stop (days)
φ_j	throughput (kt/d)
$\Delta p_{SFD-HSC}$	price differential between SFD and High Sulphur Components (HSC) ($/ton)
$C_{replacement}$	replacement costs (material and labour) of HDS/j stop (k$)

The deactivation costs do not change during optimisation.

System constraints
For the properties, see first three system model formulas, there are constraints derived from the SFD specifications:

$S_{SFD} \leq S_{SFD\ spec} - \sigma_S$ — Sulphur content of SFD is smaller than the SFD sulphur specification minus the quality margin for sulphur

$\rho_{SFD\ spec\ min} + \sigma_\rho \leq \rho_{SFD} \leq \rho_{SFD\ spec\ max} - \sigma_\rho$ — Density of SFD is between the upper and lower SFD density specification taking into account the density quality margin

$FP_{SFD} \geq FP_{SFD\ spec} + \sigma_{FP}$ — Flash point of SFD is higher than the SFD flash point specification plus the quality margin for flash point

The sigma σ represents the quality margin necessary to guarantee that a product is within specifications at the gas station. This quality margin is determined by the inaccuracy of the measurement equipment and the chance of contamination after production. The subscripts indicate the property to which the quality margin applies.

6.3 Nature of optimisation problem

When the optimisation problem is formulated, the nature of the problem should be defined. Clearly it is a constrained multivariable optimisation with equality and inequality constraints. Additionally models can be grouped according to the following types:

- Steady state versus unsteady state (static versus dynamic)
- Linear versus nonlinear
- Continuous versus discrete variables

The above optimisation model is classified as a static, continuous, nonlinear model with nonlinear constraints [Lambert, 1985; Edgar, 2001].
This classification requires some explanation:

- Static, because variables are assumed not to change in time during the use of the model. Another formulation would be that at any moment in time the output of the model only depends on the input variables at that time. Thus the model has no 'memory'.
- Nonlinear, because the objective function is nonlinear.
- With (nonlinear) constraints
- Continuous variables, this is a modelling choice. The decision variables, level of desulphurisation and blending quantities, can take any value within their limits. But for operation purposes the production settings are communicated in rough figures. A blending operator, for instance, is not told to blend 12,426.999 tons of HCU gas oil with 15,375.553 tons of Des-LGO. Instead the production settings will be blending 12.4 kiloton of HCU gas oil with 15.4 kiloton of Des-LGO. The same is valid for

desulphurisation depths, the desired level of desulphurisation should be at max one decimal precise.

Thus these variables are continuous but for operations round figures are used. It is chosen to consider all variables continuous in the optimisation as this reduces the complexity of the optimisation problem. If these variables would be considered discrete, a mixture of continuous and discrete variables would be present in the optimisation problem, requiring mixed-integer programming [Floudas, 1995]. Mixed-integer programming is far more complex than nonlinear programming (NLP) and, moreover, more likely to convergence to suboptimal solutions.

6.4 Size of the optimisation problem

The size of the optimisation problem is determined by the following:

› The criterion is one nonlinear continuous function
› Eight continuous decision variables, i.e. optimisation variables
› Fourteen linear constraints on decision variables (lower and upper limits)
› Four nonlinear equality constraints (system model)
› Four nonlinear inequality constraints (system constraints)

Compared to other optimisation problems the size of the problem at hand is considered small.

6.5 Optimisation algorithms

Now that the nature of the optimisation problem is known, the optimisation techniques suited for solving the problem are identified and one is chosen to apply. This report doesn't have the intention to discuss possible techniques of solving nonlinear optimisation problems in great detail. Two algorithms that are suited for solving NLP problems are considered [Edgar, 2001; Floudas, 1995]:

› Successive quadratic programming (SQP) methods replace a nonlinear objective function by a succession of second order approximations. These approximations apply quadratic algorithms.
› Generalised reduced gradient (GRG) methods reduce the complexity of the objective function by substituting variables and converting inequality constraints by introducing a slack argument. Hence, the reduced problem is the original problem ignoring inequalities. The GRG algorithm employs an iterative procedure of computing the gradient, the search direction and step size, see Figure 13.

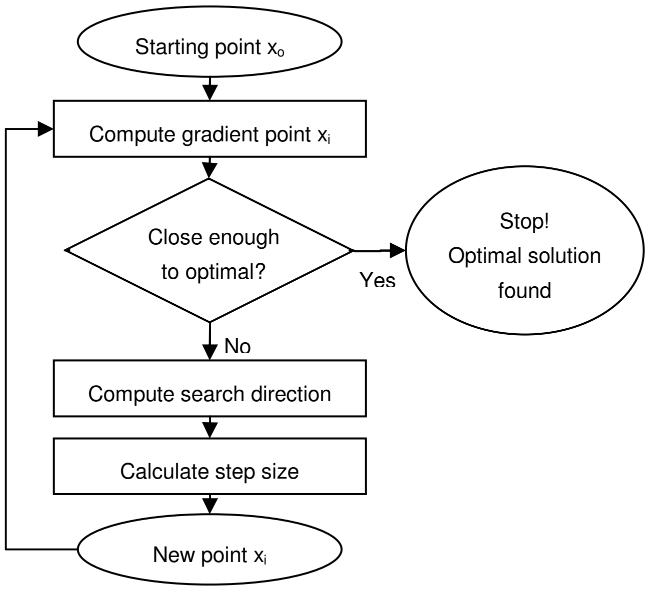

Figure 13 Generalised Reduced Gradient algorithm

These two techniques seem suitable for solving constrained nonlinear optimisation problems. The main difference between both algorithms is the way they handle constraints during the optimisation process. SQP usually generates points with large constraint violations. This shortens the time necessary for SQP to find the optimal solution, but causes difficulties for models with log or fractional power expressions, because negative arguments for these functions may be generated during optimisation. [1] The GRG method on the other hand needs to satisfy constraints at each step of the algorithm. Therefore the GRG method requires more

[1] Log and fractional power expressions cannot be calculated for negative arguments.

time to converge to the optimal solution, but it is better capable of handling log and fractional power expressions [Edgar, 2001]. Given the fact that the optimisation problem at hand contains both logarithmic and fractional power expressions (see flash point formulas), the GRG method is assumed to be best suitable.

6.6 NLP software

Now that the nature of the problem and the best suitable algorithms are known, software is considered in which the algorithm can be implemented. The following GRG-based optimisers are available:

Stand-alone operation	It's possible to develop the SFD optimiser in FORTRAN or C. But these stand-alone applications require a lot of maintenance and most (future) users of the SFD optimiser will not be familiar with these codes.
GRG2	"This code is presently the most widely distributed for the for the generalised reduced gradient […] it is the optimiser employed in the spreadsheet programs Microsoft Excel, Novell's Quattro Pro, Lotus 1-2-3." [Edgar et al, 2001, p320]. The GRG2 code is suitable for optimisation problems with only a couple *hundreds* variables and constraints. Considering the size of the optimisation problem at hand, this code seems suitable.
LGRG2	This is an extension of the GRG code, for optimisation problems with at least thousand variables and constraints. This code is far too advanced for the optimisation problem at hand.
CONOPT	Like the GRG2 code this is widely distributed. It is designed to solve large problems, like LGRG2. Again, this GRG implementation is far too advanced for the problem at hand.

Considering these GRG-based optimisers; LGRG2 and CONOPT are too advanced; and in stand-alone operation the implementation and maintenance of the SFD optimiser requires too much attention and is not user-friendly. Hence the most suitable implementation of the optimisation problem is a GRG2-based optimiser.
From the GRG2-based optimiser, assuming the functionality and reliability of all optimisers is equal, Microsoft Excel's Solver is preferable to Quattro Pro and Lotus 1-2-3. Main reason for this preference is the fact that all potential users are likely to have sufficient Excel experience. Additional advantage is that no investments (both money and time) have to been made for software licences and training programs.

6.7 Conclusion

Goal of the optimisation is to maximise the SFD optimiser margin, i.e. the total blend value minus the deactivation costs. Model requirements concern functionality, reliability, user-friendliness, feasibility, added value, and robustness.
The optimisation problem contains eight decision variables, namely levels of desulphurisation and blending quantities. It is a static, continuous, nonlinear optimisation problem with nonlinear constraints and is relatively small. The optimisation problem is solved employing the generalised reduced gradient algorithm and is implemented in GRG2, using Microsoft Excel and its Solver option.

7 Verification and validation of the optimisation model

In the previous chapter the model setup was discussed. This chapter describes the validation and verification of the optimisation model that was constructed based on that setup. The first paragraph deals with the model verification, where the model is checked for correctness and consistency. The second paragraph elaborates on the model validation, where model reliability and sensitivity is checked.

7.1 Verification

Verification of the optimisation model is an evaluation step that checks the correctness and consistency of the model. Modelling inconsistencies sometimes are very obvious (e.g. division by zero in Excel results in *#DIV/0!*). These errors were corrected during the model construction. After the optimisation model is finished it should be subjected to a number of tests. A first verification test discussed here is checking the scaling of variables. Variables should be the same order of magnitude, for instance kilograms cannot be added to tonnes). A second verification test is the dimension analyses, which checks if the dimensions on the left and right side of equations correspond. Below the dimension analysis of the objective function is given. Shown is that the dimensions in the objective function on both sides match.

$$M_{SFD} = \sum_{i=1}^{5}(p_i * q_i) - \sum_{j=1}^{3}\left(\frac{C_j}{RL_j(x_j)}\right) + R_{LGO}$$

$$k\$/w = \$/t * kt/w \quad - \quad k\$/w \quad + k\$/w$$

$$k\$/w = k\$/w \quad - \quad k\$/w \quad + k\$/w$$

$$k\$/w = k\$/w$$

This dimension check is done for all model equations. They were all found correct.

7.2 Validation

After the model verification is executed successfully the model validation can start. Validation can be considered as a qualitative validation to check if the model is plausible and reliable. Many validation tests exist; four are described in this paragraph.

Extreme value analysis

The extreme value analysis is a very effective way to check if the model behaves like expected. Often it is hard to predict the expected outcome for small input changes, but for extreme changes it is easier to form an expectation. Parameters and variables are set to extreme numbers like zero or extremely positive or negative numbers. Setting, for instance, all eight decision variables to one billion minus resulted in the same optimal solution as any value within the constraint values. The time the SFD optimiser needs to converge to an optimum is longer though; but still a matter of seconds. Besides the decision variables also the parameters (input data) were set to extreme values. The model demonstrated to be able to converge to the optimal solution in all situations. Thus the SFD optimiser passed the extreme value test.

Sensitivity analysis

The second validation test performed was the sensitivity analysis. The sensitivity of both the objective function and the system model are considered for changes in the decision variables and parameters. First the sensitivity of the system model is examined as the system model determines how the objective function behaves. There are a number of things interesting to note regarding the system model. First of all the impact of the level of desulphurisation on the HDS catalysts' run length and the deactivation costs are described (see the figure below).

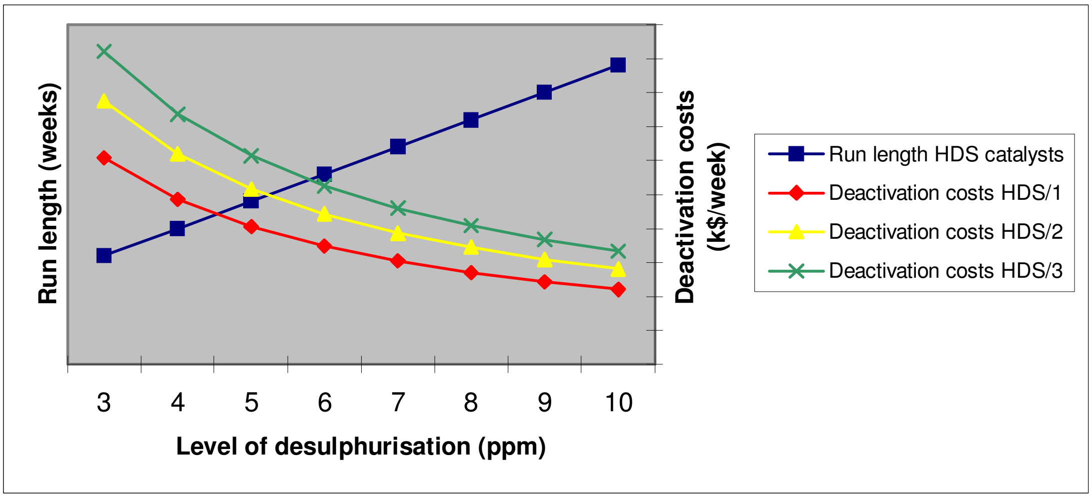

Figure 14 Impact of level of desulphurisation on catalyst run length and deactivation costs

The figure demonstrates that the SFD optimiser applies a linear approximation for the relation between run length and the level of desulphurisation. In paragraph 6.1 this was already discussed. See Appendix 7 for a survey on this approximation. Looking at the deactivation costs, significant differences exist between the HDS's. These differences can be explained by the differences in replacement costs and the loss of income. It is interesting to see that desulphurising to 7 ppm on HDS/1 is cheaper than desulphurising to 9 ppm at HDS/3. The user of the decision support tool should keep this in mind during the formation of the feasible optimal solution (see §8.1.3).

Another characteristic of the system model should be noted: the properties of the SFD blend are the weighted average of the properties of the diesel components. As al least two thirds of the quantity diesel blend is light gas oil, this stream has a large impact on the end properties of the SFD blend. The Des-Kero stream, on the other hand, at most only accounts for nine percent of the total diesel quantity. This means that to lower the sulphur content of the SFD blend by 1 ppm the sulphur in the Des-Kero should drop 11 ppm. Hence the impact of the Des-Kero properties is limited. The HCU gas oil is at most eighteen percent.

The second kind of sensitivity analyses focuses on the objective function and examines the sensitivity of the objective function for changes in decision variables. Two factors determine the SFD optimiser margin (the objective variable), namely deactivation costs and the blend values of the diesel components. When the blending becomes constraining on sulphur, density and/or flash point, the optimiser makes a trade-off between additional deactivation costs and additional blend value. Imagine the situation in which the effluent of the HDS's count 7 ppm sulphur and an upset occurs in the HCU, resulting in a sulphur content of 50 ppm in the HCU gas oil. In that case the major part of the HCU gas oil should be downgraded to the industrial gas oil pool. This downgrading could be reduced by increasing the reactor temperature at the HDS's to desulphurise to 6 ppm. This raises the deactivation costs with some thousands of dollars a week. But it enables to blend more HCU gas oil and Des-Kero in the SFD blend, raising the total blend value with more than hundred thousand a week, leading up to a net gain of approximately hundred thousand a week. Hence at current prices it is profitable to blend the maximum HCU gas oil and Des-Kero in the SFD blend at the expense of deactivation. If in the future the differentials between the values of diesel components in the different end product pool decrease, it can occur that the additional blend value is not sufficient anymore to compensate for the additional deactivation costs.

Appendix 8 contains the sensitivity and answer report provided by Microsoft Excel's Solver. Bases for these reports was a scenario in which during normal operations (HCU gas oil holds 5 ppm sulphur) a HCU upset occurs and the sulphur content in the HCU gas oil raises to 50 ppm. The SFD optimiser is used to calculate the optimal production settings during the upset situation. From the two reports a number of interesting conclusions can be drawn:

› The solution provided by the SFD optimiser is constrained on both sulphur and flash point, with a small density give away. Hence give away is minimised by the optimiser.
› Lowering the quality margin on sulphur by one ppm (thus the sulphur target equals 9.5 ppm) results in an additional gain of more than hundred thousand dollar a week. This can be explained by the fact that less effort needs to be made for desulphurisation.
› Increasing the lower limit of the desulphurisation in the HDS's by one ppm decreases the SFD optimiser by 26 thousand dollar a week for HDS/1 and HDS/2, and 34 thousand dollar a week for HDS/3. Reason for this is that the HDS's can desulphurise less and thus more HCU gas oil should be downgraded and less Des-Kero can be blend in the SFD pool.
› An increase of the weekly HCU gas oil production by one kiloton leads to an additional margin of more than 400 thousand dollar a week.

Designed experiment

In additional to the sensitivity analysis a designed experiment was executed to determine if the model would react as expected at turning points in the input data. Currently kerosene is more valuable in the diesel pool, then elsewhere. But what happens if the value of Kerosene in Jet A1 becomes equal or higher than the value of Des-Kero in the diesel blend. The designed experiment, enclosed in Appendix 9, examined the behaviour of the model around such turning points. If, for instance, the value of kerosene in Jet A1 becomes higher than the value of Des-Kero in the SFD blend, all kerosene is utilised for the Jet A1 production. The value turning point of other diesel components and their properties were also examined. The conclusion was that the model behaved as expected around such turning points.

Experts

The fourth validation method applied is the consulting of experts to check (the confidence in) the model reliability. The technologists of the production units responsible for the desulphurisation of light gas oil (RTC) and blending (RBL), a process controller of the HDS's, a catalyst expert, personnel of the economics and planning department were all consulted. The model was also discussed during a plenary meeting. Suggestions for improvements derived from those consults were utilised for model improvement. The final model is a decision support tool that can count on the confidence of the consulted experts. It is assumed to be valid and reliable.

7.3 Conclusion

The model is correct as well as consistent. Moreover the model behaves as expected; even in extreme conditions and around turning points. Experts have confidence in the model. Hence the model is considered to be valid. Interesting insights obtained during the validation are:

› The SFD optimiser is reliable and fast no matter what the input is.
› Desulphurisation in HDS/3 is more expensive than HDS/2, and HDS/2 is more expensive than HDS/1.
› In case the diesel blending is sulphur constrained the SFD optimiser makes a trade-off between additional deactivation costs and additional blend value. Additional deactivation costs depend on the level of desulphurisation and the additional blend value depends on value differentials.
› Decreasing the quality margin results in high additional gains.

8 Decision support by SFD optimiser

In the previous chapters the decision support tool, the SFD optimiser, was constructed and validated. This chapter elaborates on the tool itself; estimates the potential gains it can lead to; describes its implementation; reflects on the model requirements introduced in paragraph 6.1 and concludes with the potential of the decision support tool to be generalised.

8.1 SFD optimiser

This paragraph describes who is going to use the SFD optimiser, its global lay-out and how it is going to be used.

8.1.1 User

As already mentioned in paragraphs 4.6 and 6.1 the SFD optimiser is going to be used by the economics and planning department on a weekly basis. The days before the new production settings are put into action; the LP tool generates estimates for properties, for blend values of diesel components, and for quantities of intermediate products produced. The scheduler responsible for the diesel production enters these data in the SFD optimiser and runs the model. The decision made based upon the SFD optimiser's advice is noted in the production settings.

8.1.2 Interface

In paragraph 6.6 was chosen for implementation of the SFD optimiser in Microsoft Excel. The SFD optimiser's spreadsheet consists of several worksheets. Three worksheet categories can be distinguished: input worksheets, the advice worksheet and internal worksheets. Screenshots of these worksheets can be found in Appendix 10. Here the philosophy behind the worksheets is described. The role of the model user is crucial as the success of the optimisation model depends on its user. Therefore user-friendliness, besides functionality and reliability (see paragraph 6.1) is a main model requirement. Several features contribute to the user-friendliness:

› Visual distinction between cells by the use of colours and borders. Cells that should and can be altered by the user are indicated in green, similar to the models and spreadsheets already in place at the economics and planning department.
› Cells that should not be altered are protected; they cannot be altered unless worksheet protection is disabled.
› Information is added to most cells. When the user selects a cell, a description and requirements of that cell are given. For instance *this cell contains the blend value of HCU gas oil in the SFD blend; the unit is US dollars per ton and the value varies between 100 and 1000*. This information helps the user in case he/ she is unfamiliar with the tool. This is important as the schedulers rotate frequently (once a year or every two years) and in case of absence others temporarily substitute.
› Data validation: a protection is used to minimise the chance of wrongly entered data in cells; for most cells lower and upper limits are set. For instance the quality margin for sulphur has a lower limit of 0 and an upper limit of 5. In case the user wants to enter 0 but hits the wrong button and enters 9, the model gives a warning *Unlikely value entered*.
› Optimise-button: for optimisation a button is used, that holds code that automatically optimises correctly. Therefore the user does not have to open the Solver option[1] in Excel and enter all optimisation specifications.
› Fast to use: as the model is not only easy to use, but also converges to an optimum in several seconds, the waiting time is minimised and thus the user-friendliness safeguarded.

[1] Prerequisite for the use of the SFD optimiser is that the add-in Solver is enabled.

Hence it can be concluded that much is done to assure user-friendliness of the SFD optimiser.

8.1.3 <u>How to use</u>

This paragraph is not a manual, but explains the general procedure of the use of the SFD optimiser. Figure 15 shows this procedure.

Step 1 Update the master input data: this is the first input worksheet. Here data is entered that changes on a less regular than on a weekly basis, e.g. product specifications, catalyst run lengths.

Step 2 Update the weekly input data: this is the second data worksheet. It contains data that should be updated on a weekly basis, e.g. blend values, component properties and quantities produced.

The next three steps all take place in the advice worksheet.

Step 3 Optimise: the advice worksheet contains two sets of data: the optimal solution and the feasible solution. When all data are updated the user should optimise using the optimise-button. The optimal solution data are updated. But the optimal solution may not always be a feasible or preferable one. The user, the diesel scheduler, is most equipped to make this judgement.

Step 4 Change the decision variables: as the optimal solution must be converted to a feasible one, e.g. rounding of the optimal solution. Hence the user changes the decision variables, i.e. levels of desulphurisation and blending quantities.

Step 5 Check constraints: changing the decision variables also affects the properties of the blend, the quantities of components utilised and the SFD optimiser margin. During the changing of the decision variables, constraint variables that are violated become red, indicated that they are violated. Thus the user should check that all constraints are satisfied. If one or more constraints are violated, the user should return to step 4 etc. This is an iterative process, in which the user can see the impact of changing the decision variables on the SFD optimiser margin and on constraints.

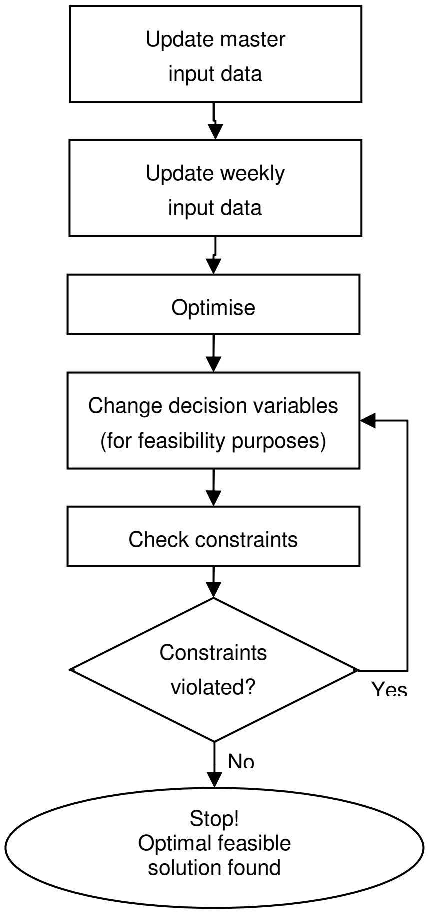

Figure 15 Optimisation procedure

Stop! When the optimal solution is successfully (no constraints are violated) converted into a feasible one, the new production settings regarding the sulphur free diesel production are found.

8.2 Gains

To be successful the decision support tool should generate additional margin and improve the decision-making process done by the economics and planning department. This paragraph elaborates on the monetary and non-monetary gains of the SFD optimiser.

The SFD optimiser is an initiative of the Global Margin Improvement (GMI) programme (see §2.5). In the project proposal for the SFD optimiser the estimated annual benefit was

approximately $850,000. Recalculating this estimate for current prices the annual benefit would be ca. 1.1 m$/y, based on a) an expansion of HDS catalyst run length by 2 month (ca. k$500/y) and b) an expansion of time that HCU gas oil can be blend in diesel for two months more (ca. k$600/y). This equals an increase of refinery margin by 0.73 $c/bbl.[1]
But now that the optimisation model is build, more accurate estimates can be made for the potential gains of the SFD optimiser. For these estimates a reference scenario is used, derived from the scouting study for the SFD introduction [Azodi, 2003]. In this scouting study the SFD production *without* the SFD optimiser is described. In that case the situation was as follows:

› The HDS's would desulphurise in a steady state, to a sulphur content of 7 ppm.
› The production of Des-Kero would be characterised by a 12-day cycle. Ten days the HDS/4 would be utilised for Jet A1 production and two days for the desulphurisation of kerosene for the diesel pool. Given the maximum throughput of HDS/4 the weekly available quantity of Des-Kero that can be blend into the diesel pool would be X kiloton.

The SFD optimiser does not consider these two factors fixed but rather flexible depending on economics and component properties. To obtain a better idea of the potential gain of the SFD optimiser the reference case above, i.e. fixed HDS depths and Des-Kero production, is compared with the advice generated by the SFD optimiser. This comparison is done for five scenarios, in which the sulphur content of the HCU gas oil rises from 5 ppm to 50 ppm.[2]

HCU gas oil = 5 ppm S

	HDS depth (ppm)	HCU gas oil in SFD (kt/w)	Des-Kero in SFD (kt/w)	Delta margin (k$/w)
Reference	7	Max	X	0
Optimiser	9,6	Max	X+1	117

In case the sulphur content of the HCU gas oil would be 5 ppm, which corresponds to the period right after the HCU catalyst is changed, the optimiser advises to desulphurise the light gas oil to 10 ppm thus saving deactivation costs. Furthermore the quantity of Des-Kero that can be blended into the SFD pool is one kiloton higher.
In total the estimated gain of the SFD optimiser during the start of the HCU catalyst run length is approximately 120 thousand US Dollar a week.

HCU gas oil = 10 ppm S

	HDS depth (ppm)	HCU gas oil in SFD (kt/w)	Des-Kero in SFD (kt/w)	Delta margin (k$/w)
Reference	7	Max	X	0
Optimiser	8.3	Max	X+1	105

In case the sulphur content of the HCU gas oil would be 10 ppm, which corresponds to the sulphur content of the HCU gas oil after circa two years, the optimiser advises to desulphurise the light gas oil to 8.3 ppm thus saving deactivation costs. Furthermore the quantity of Des-Kero that can be blended into the SFD pool is one kiloton higher
In total the estimated gain of the SFD optimiser halfway the run length of the HCU catalyst is more than 100 thousand US Dollar a week.

[1] In order to calculate the additional refinery margin the annual gain should be divided by the number of barrels processes at Oil & Co Refinery, i.e. 150 million barrels a year.
[2] For the calculation of the gains the prices at the end of 2004 were used.

HCU gas oil = 17 ppm S

	HDS depth (ppm)	HCU gas oil in SFD (kt/w)	Des-Kero in SFD (kt/w)	Delta margin (k$/w)
Reference	7	Max – 3	X-0.4	0
Optimiser	6.6	Max	X+1	233

In case the sulphur content of the HCU gas oil would be 17 ppm, which corresponds to the sulphur content of the HCU gas oil at the end of the HCU catalyst's run length (i.e. 4 year), the optimiser advises to desulphurise the light gas oil to 6.6 ppm thus increasing the deactivation costs. On the other hand the quantity of HCU gas oil that can be blend into the SFD pool is higher and therefore also the quantity of Des-Kero is higher, which results in a significant additional blend value. In total the estimated gain of the SFD optimiser at the end of the HCU catalyst's run length is approximately 230 thousand US Dollar a week.

The previous three scenarios simulated normal operations sulphur content in the HCU gas oil, but it is also interesting to look at the added value of the SFD optimiser in case of HCU upsets. Two situations of recent history are used:

HCU gas oil = 33 ppm S

	HDS depth (ppm)	HCU gas oil in SFD (kt/w)	Des-Kero in SFD (kt/w)	Delta margin (k$/w)
Reference	7	Max-9.4	X-3.7	0
Optimiser	6	Max-7.2	X-2.7	169
	5	Max-5.1	X-1.5	329

In case the sulphur content of the HCU gas oil would be 33 ppm, the quantity of HCU gas oil is sulphur constrained. The HDS capacity is not expected to be sufficient to desulphurise to blend the total quantity of HCU gas oil in the SFD pool. What the actual capacity of the HDS's is still unknown so two possibilities are considered. The lower limit to the sulphur content in the HDS effluent is set on 6 ppm and 5 ppm respectively.
In case 6 ppm is the lower limit the deactivation costs rise, but the estimated blend value increases, leading up to a gain of circa 170 thousand a week. If the lower limit is 5 ppm the additional margin is almost 330 thousand US Dollar a week.

HCU gas oil = 50 ppm S

	HDS depth (ppm)	HCU gas oil in SFD (kt/w)	Des-Kero in SFD (kt/w)	Delta margin (k$/w)
Reference	7	Max-10.8	X-4.4	0
Optimiser	6	Max-9.5	X-3.7	97
	5	Max-8.2	X-3.1	180

In case the sulphur content of the HCU gas oil would be 50 ppm, the quantity of HCU gas oil is even further sulphur constrained. In case 6 ppm is the lower limit the deactivation costs rise, but the estimated blend value increases, leading to a net gain of 97 thousand a week. If the lower limit is 5 ppm the additional margin is 180 thousand US Dollar a week.
To conclude, it can be said that in all situations considered the SFD optimiser raises margin significantly. To estimate the annual gain and the additional refinery margin, we assume normal operations thus no upsets. Taking the average over the four year run length of the HCU catalyst this leads to an annual gain of approximately 9 million US dollars a year. This corresponds to an additional refinery margin of 6.3 $c/bbl. It should be noted that these

estimates are based on current prices. This additional refinery margin equals to one eight of the total aim of the Global Margin Improvement programme, namely a raise by 2007 of 50 dollar cents per barrel.

Besides monetary gains, the SFD optimiser also results in a number of non-monetary gains:

a. Combining the cost-perspective of RTC with the margin-perspective of REP: the SFD optimiser includes both deactivation costs and blend value, thus including the interests of both the production unit responsible for desulphurisation of light gas oil, RTC, and the economics and planning department. This may improve the cooperation and relation between the two. Maintaining good relations with production units is also a goal of the economics and planning department (see chapter 4).
b. Contribution to objectives of the economics and planning department: besides improving relations, the decision support tool contributes to the realisation of some REP-specific goals. The SFD optimiser contributes to more accurate decision-making by the support of a tool that is reliable, easy to use, fast and value adding. It provides more accurate estimates regarding the sulphur free diesel production that the current application (LP tool) used for planning and scheduling purposes.
c. Insights relevant for the long-term planning of catalyst replacement stops: the SFD optimiser can be used to comprehend the impact of deeper desulphurisation for the catalyst run length. Based on these insights decisions can be made for the number and the moment of HDS maintenance stops (e.g. catalyst replacement stops).
d. Insights in potential improvements: the SFD optimiser can be used to see the economic impact of improvements, like deeper desulphurisation or lower quality margins. The validation tests already showed that in case of upsets lowering the quality margin results in significant gains (approximately 100 thousand US Dollar a week). In normal operations these gains vary between 2 and 20 thousand a week.

8.3 Implementation

Regarding the implementation of the optimisation model in the OCR organisation the following remarks are made:

- The model is mastered by the Refinery Economics and Planning (REP) department. Every week they will update the model input, run the model, convert the optimal solution in their preferable solution and communicate these settings to the relevant production units.
- The weekly input is derived from the scheduling and planning tool PIMS (a newly developed LP tool), also mastered by REP. This tool generates estimates for product stream properties and values of product streams. Some values may not be provided by the PIMS tool. These missing data are generated by applying the marginal economic tool also mastered by REP.
- The master input should be checked less regularly, for instance, once every three months. Standard forms can be made to determine which data is needed and who is responsible for providing this data.
- The desired levels of desulphurisation on the HDS's for the coming week are part of the model outcome and should be communicated to the production unit Refinery Treating and Conversion (RTC) together with the other production settings. RTC should set the advised desulphurisation depth as targets for the automated control systems (SMOC's) on the HDS's. The level of accuracy of the HDS depth is optional, but recommended is one decimal precise.
- The quantity of Des-Kero that should be produced in the coming week is also a decision made on basis of the model outcome and should be communicated, together with the other production settings, to the production unit Refinery Utilities and Distillation (RUD).

The composition of the diesel blend can be communicated to the production unit Refinery Blending and Logistics (RBL) as an advised blend. But because the blending at RBL is automated this advice should only function as a guideline. A possible guideline could be *blend maximum quantity of HCU gas oil and maximum quantity of Des-Kero in the diesel blend* or another guideline could relate to the priorities of alternative destinations, e.g. *HCU gas oil preferably to diesel, otherwise to industrial gas oil pool and if this is not possible it should be utilised as LO feed*.

In addition to the implementation aspects above, the student will stay some weeks after his graduation. It is the student's intention to, during these weeks, pass on the SFD optimiser to the diesel scheduler, to write manuals, to further improve the SFD optimiser according to user wishes and to give inform and brief the operational staff, especially of RTC, about the introduction of the sulphur free diesel production and the SFD optimiser.

8.4 Reflection regarding model requirements

This paragraph evaluates the extent to which the SFD optimiser satisfies the model requirements introduced in paragraph 6.1. Table 5 summons the six requirements and the extent to which these requirements are satisfied:

Table 5 Reflection on model requirements

Requirement	Score
Functionality	Maximum, optimal solution is calculated and a feasible solution can be found and compared.
Reliability	SFD optimiser passed all tests and experts have confidence in the tool.
User-friendliness	Utmost is done to safeguard user-friendliness. The result is very satisfactory.
Feasibility	No feasibility difficulties are foreseen. Implementation is already prepared.
Added value	Additional refinery margin of circa 6.3 $c/bbl; contribution to realisation actor goals.
Robustness	The life span of the tool is assured; when no input data is available, rough estimates should be used.

Below this table is explained in more detail

- Functionality: goal of the SFD optimiser was to calculate the optimal production settings for the sulphur free diesel production. The decision support tool indeed generates the optimal solution with the highest SFD optimiser margin, i.e. total blend value diesel components minus the costs of desulphurisation. In addition the SFD optimiser gives the user the possibility to alter the production settings to a feasible solution and compare this with the optimal solution.
- Reliability: the SFD optimiser passed the tests of verification and validation and OCR personnel has confidence in the reliability of the model. Hence, the model is assumed to be reliable.
- User-friendliness: during the development of the SFD optimiser the user-friendliness was considered a core value. As described in paragraph 8.1 maximum was done to assure the user-friendliness. The SFD optimiser is considered easy to use, easy to maintain, easy to comprehend and is build in a familiar environment, namely Microsoft Excel. Hence the SFD optimiser is assumed to be very user-friendly.
- Feasibility: the SFD optimiser is made compatible with the Oil & Co's standardised computers and it connects nicely with the data generating tool, PIMS, which provides the weekly input data. No feasibility difficulties are expected. Hence the implementation, use and maintenance of the decision support tool are considered feasible.
- Added value: as shown in paragraph 8.2 the potential monetary gains are significant: estimated additional refinery margin at current prices is estimated to be 6.3 $c/bbl.

The SFD optimiser contributes to the realisation of the goals of actors involved in the diesel production. The deactivation costs of RTC are taken into consideration and the margin, for which the economics and planning department is responsible, is also safeguarded.

- Robustness: given the data protection, the protection of the SFD optimiser spreadsheet (both worksheets as whole file), potential sources of damage to the tool are prevented and thus the life span assured. In case no input data is available, the user can best decide which estimates should be used for optimisation. If operations is in a steady state data from the former optimisation run can be used or estimates based on the user's knowledge and intuition can be utilised. Note that the chance that no data is available is small, as this means the complete decision-making process by the economics and planning department is disrupted.

Hence the SFD optimiser satisfies all requirements. But, of course, actions could be made to improve the performance of the tool. To increase the functionality of the tool dynamics could be included in the model (e.g. the deactivation mechanism of catalysts). Also the scope of the tool can be enlarged, for instance by including also HDS/4 and the HCU. Reliability can be further checked by comparing the model output with actual data. This only becomes possible after the SFD production has started. User-friendliness can be further improved by learning the (potential) users to understand and to use the tool. Feasibility do not exist in the present form of the decision support tool, but may arise in case a dynamic model is developed. The added value can be verified by recalculating the monetary gains for current prices and for long term steering values. The robustness can be further assured by installing the tool on the schedulers' computers and making sure everything works. These further improvements are embedded in the recommendations in the last chapter.

8.5 Generalisation

This paragraph examines the extent to which the SFD optimiser can be generalised and used for other refineries and/or processes.

Considering that Oil & Co Refinery is one of the biggest refineries in the world and unique in its composition, the SFD optimiser cannot be applied to other refineries (or processes) without the necessary adjustments. Regarding the sulphur free diesel production the process line-up and the HDS capacity contribute to the uniqueness of Oil & Co Refinery. At other refineries other issues and challenges matter. The approach and development of the decision support tool described in this report can be applied to a wide variety of production processes, but a decision support tool for process optimisation should be tailor-made in order to be successful. Hence, the research approach presented in this report can be generalised, the SFD optimiser itself (without adjustments) cannot. Also the organisational review is specific for Oil & Co Refinery and the sulphur free diesel production.

9 Organisational review of the incorporation of SFD optimiser

In the previous three chapters the design, construction and validation of the SFD optimiser was described. Outcome was an optimiser that passed the tests of validation and that could lead to significant gains. This chapter explores the incorporation of the SFD optimiser in the refinery's organisation and examines the chance that the potential gains are realised. For basic information about the organisation the reader is referred to paragraph 2.2.3 and chapter 4. In the first paragraph the consequences of the decision support tool for the organisation is discussed. The second paragraph investigates if the incentive structure of the refinery is effective and correct. The third paragraph estimates the chance of successful incorporation of tool in the refinery organisation and does some recommendations. Two basic assumptions are made for this organisational consideration: firstly this chapter assumes that the newly designed system of key performance indicators is already applied. Secondly the actors considered correspond to the main actors identified in paragraph 2.2.3 and discussed in chapter 4.

9.1 Consequences of decision support tool

The incorporation of the decision support tool, the SFD optimiser, has consequences for operations, objectives, decision-making, cultural differences, and the site-wide performance. These consequences determine for a great deal the reception of the SFD optimiser in the organisation.

9.1.1 Consequences for operations

The most important consequences of the SFD optimiser for operations are:

- Less steady state operations: as the level of desulphurisation in the HDS's and the quantity of kerosene produced can vary from week to week. This requires operational flexibility from RTC and to smoothly operate the communication and cooperation with the economics and planning department must be good.
- Less quality give away: the SFD optimiser minimises the give away on one or two properties.
- Smaller margin to compensate disruptions: less give away implies that the margin for compensating irregularities is also minimised. Thus to prevent and resolve disruptions, and minimise the loss of income the communication between the five actors becomes more critical. The communication will be optimal if the main force between the actors is cooperation.
- As none of the main actors can assure the diesel quality by itself, as steering instruments to compensate for disruptions are spread over the actors, the diesel quality is a shared responsibility. Again, cooperation and good communication become more crucial.
- More likely conflicts in unit utilisation: most HDS's are used for multiple purposes. HDS/4, for instance is used for both the Jet and Des-Kero production and HDS/3 is used for both light gas oil and SBP Kero production. These alternative uses of units may conflict. These conflicts already existed in the old diesel production, but now become more relevant as HDS capacity becomes a limited factor. Regarding the sulphur free diesel production this mainly causes problems for RTC who is responsible for HDS/1, HDS/2 and HDS/3. To prevent such conflicts the communication and relation between RTC and the economics and planning department must be good.
- Importance monitoring deactivation data: at present the HDS technologist gathers deactivation data on a weekly basis and extrapolates this data to estimate the catalyst run lengths and provide feedback to the catalyst experts who predict deactivation. In the future such feedback should also be provided to the economics and planning department, so that they can keep the SFD optimiser up to date.

9.1.2 Consequences for objectives

The decision support tool has impact on a number of the objectives introduced in paragraph 4.2. Here the impact on the relevant goals is discussed:

Optimal decision support

The economics and planning department has to account for the accuracy of its prediction and estimates. The SFD optimiser improves the decision support for the sulphur free diesel production and thus contributes to the realisation of the objectives of the economics and planning department.

Maximal consideration targets production units

The SFD optimiser contributes to another goal of the economics and planning department, namely the good relation with the production units, as it takes its decisions not only on basis of hydrocarbon margin, but also the operational costs of desulphurisation.

Minimal quality give away

The sulphur give away is minimised by the SFD optimiser and often, also one of other two properties, i.e. flash point and density, becomes constraining. Hence often there is only give away on one of the three constraining properties. Minimisation of give away is a site-wide goals as well as a goal of REP.

OA ≥ target

Refinery Treating and Conversion, RTC, is confronted with flexible temperatures. The effect of these fluctuations on the chance of upsets, thus operational availability, is unknown. Assuming that the desulphurisation targets only change once or twice a week and in controlled situations, the effect on the operational availability of RTC is assumed to be negligible.

Costs ≤ budget

The net effect of the flexible level of desulphurisation on deactivation costs of RTC is ambiguous. In the beginning of the HCU catalyst run length, the level of desulphurisation is probably lower. But when upsets take place the level of desulphurisation may be higher. Unknown is which effect is greater, the saving run length by lower desulphurisation or the loss of run length by deeper desulphurisation.

Maximal profit

A main goal of the SFD optimiser was to contribute to the realisation of the site-wide objective of maximal profit. The SFD optimiser optimises the trade-off between hydrocarbon margin and deactivation costs.

Good communication

The importance of good communication was already mentioned in the previous sub paragraph. The introduction of the SFD optimiser makes this realisation of this objective (of the economics and planning department) more crucial.

9.1.3 Consequences for decision-making

The SFD optimiser aims to support the decision-making done by the economics and planning department regarding the sulphur free diesel production. The decision-making process described in paragraph 4.3 does not change itself, rather the scope and base of the decision-making. Here the consequences of the SFD optimiser for the decision making are mentioned:

› Catalyst lifecycle economics, i.e. deactivation costs, are included in the weekly decision making. In the past the main focus of the decision-making done by REP was margin, neglecting the cost-focus of the production units. The SFD optimiser combines both perspectives.
› The decision support tool enlarges the control of the economics and planning department on operations, as it provides a better basis for steering on site-wide performance.

- As already mentioned under the operational consequences, the margin for compensating upsets is decreased. Therefore the communication and decision-making in case of disruptions should be intensified and accelerated.
- Besides for the formation of the weekly production settings, the SFD optimiser should also be used in case of disruptions in the schedule. If, for instance, the HCU has an upset resulting in sulphur rich HCU gas oil, the SFD optimiser can determine to what extent it is economically attractive to increase desulphurisation on the HDS's to compensate for the sulphur rich HCU gas oil.
- The decision support tool can, besides supporting the short term decision-making, also support the long term planning of the maintenance stops. The SFD optimiser enables REP to make a trade-off between the additional blend value due to deeper desulphurisation and the run length of catalysts. As the gradual increase in sulphur content of the HCU gas oil is roughly known (see Figure 3), the SFD optimiser can be used to estimate the desired level of desulphurisation for the coming period and hence insight in catalyst run length is obtained.

9.1.4 Consequences for cultural differences

In paragraph 4.5 the refinery organisation was described in terms of five cultural differences. Here the consequences of the SFD optimiser for those cultural dimensions are discussed briefly. Firstly the nature of the actors: the distinction between the production units and the economics and planning department (a staff department) endures, but decision tools like the SFD optimiser can close the gap between them by combining both the cost-focus of the production units and the margin-focus of the economics and planning department. Secondly the structure: in paragraph 4.5 the refinery was considered a professional network [de Bruijn, 1999] and a mixture of a professional bureaucracy and a division structure [Mintzberg, 1983]. In the professional network the SFD optimiser improves the cooperation between the different actors. Regarding Mintzberg, the decision support tool does justice to the different perspectives of the professionals, and at the same time increases the (hierarchal) steering over the divisions. The third dimension is formal organisation. Still REP is focused on hydrocarbon margin and production units on costs and operational availability. But in the second quarter of 2005 the new performance assessment system[1] is put into action. This system aims to (partly) restore the balance between the four key performance indicators (see also 4.2.2). Hopefully this balance contributes to better cooperation between the economics and planning department and the production units. The fourth dimension was occupational of nature: the expertise differences persist. Operators will always have more practical and operational knowledge that site-wide decision-makers. One of the future challenges is to stimulate the knowledge sharing between all expertise groups (operators, engineers and economists) as well as between divisions (RTC, RUD, RCP, RBL and REP). The fifth dimension, topography, does not change.
Hence subtle changes can be seen for the cultural differences in the refinery.

9.1.5 Contribution to future challenges and performance improvement

In paragraph 2.4.6 a number of future challenges were identified and paragraph 2.5 discussed the potential performance improvement by a decision support tool. This sub paragraph elaborates on how the SFD optimiser contributes to dealing with the future challenges and how it improves performance. Firstly the decision support tool increases the understanding of the sulphur free diesel production and its consequences for operations, thus decreasing the lack of experience and date. Secondly the SFD optimiser provides insight in the (economic) impact of quality margins. Thirdly it helps minimising the quality give away on sulphur, density and flash point. Fourthly the SFD optimiser includes both the perspective of

[1] The old performance assessment system is not considered in this report as the new system will already be operative before the sulphur free diesel production is started.

production units and the economics and planning department, thus enabling them to cooperate better. Furthermore the organisational review in this chapter is going to provide some recommendations to guarantee the site-wide performance.

9.2 Improvement of performance assessment

In paragraph 4.2 the site-wide objectives and the delegation of these objectives through key performance indicators was discussed. Although delegation of responsibilities can be a very effective tool to achieve one's goals, the use of key performance indicators also imposes a treat. Key performance indicators and the delegation of such indicators can lead up to perverse effects; effect that were intended and lead to suboptimal overall performance. Downs [1967] and Allison [1971] describe these perverse effects as bureau politics. Applying the bureau politics notions to Oil & Co Refinery, the refinery should be considered as a political playing field of the organisation parts, matching with the professional network from paragraph 9.1.4. Key performance indicators are subject to this strategic behaviour. Good example of this bureau politics occurs especially at the end of the year when organisation parts get insight in the extent to which they are going to realise their targets. In case the performance on one or more targets is far below par there is a high chance of strategic (political) behaviour of actors. Imagine a situation as presented in Figure 16: unit B of production unit Y is down because of a malfunction and production unit runs its unit (B) on full capacity in order to realise the target for operational availability. This suboptimal situation is caused by strategic behaviour to maximise the individual performance. As production units are assessed based on their own performance rather than the site-wide performance the occurrence of such behaviour is not excluded.

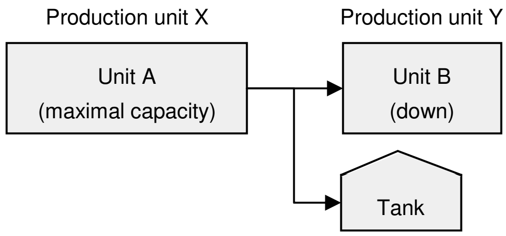

Figure 16 Suboptimal site-wide performance

De Bruijn [2001][1] identifies three design principles for successful performance assessment: mutual trust between the assessor and the assessed; variety of performance indicators; and dynamics in the performance assessment. The assessor (refinery management) trusts that the production units act in favour of the site-wide objectives. The production units accept (most of) the decisions made by the top. Hence it is assumed that there is no lack of trust. As already described in the previous paragraph the SFD optimiser may contribute to this mutual trust. Also a variety of performance indicators is applied. As already discussed in chapter 4, differentiation is made for the assessment of production units and staff departments. Similar to the economics and planning department, the other staff department have task-specific performance indicators. Hence a variety of performance indicators exist. The third design principle, dynamics, is absent. Dynamics means flexibility: inclusion of the process of establishing performance in the assessment. Regarding the refinery not only the performance on key performance indicators should be considered at the end of the year, but also the way this performance is achieved. If the realisation of one's targets resulted in suboptimal site-wide performance, this actor should be negatively assessed. While an actor that did not realise targets, but contributed to the optimisation of site-wide performance, should be rewarded.

9.3 Chance of successful incorporation of the SFD optimiser

During the development of the SFD optimiser, much was done to maximise the chance of a successful incorporation in the OCR organisation: different actor perspectives were combined; requirements for successful decision support tools were satisfied, etc. Paragraph

[1] De Bruijn (2001) wrote a book on performance assessment in the public sector. The research mainly focuses professional organisations. The discussion on performance assessment stays very generic. Part of the examples convern the public sector, others consider the private sector. It is assumed that this book can also be applied to professional bureaucracies like Oil & Co Refinery.

9.1 showed that the consequences of the SFD optimiser are mostly positive, but some imposed challenges. To implement the SFD optimiser successfully these challenges should be dealt with adequately. Paragraph 9.2 considered the incentive structure of Oil & Co Refinery and mainly concluded that a level of dynamics is missing from the performance assessment system; not only the performance, but also the process of achieving that performance should be considered. This paragraph does some recommendations to further increase the chance of successful incorporation and hence assuring that the potential gains of the SFD optimiser are realised. First the consequences from paragraph 9.1 are discussed, then the inclusion of dynamics is described and some practical challenge is used to wind up.

The success of the SFD optimiser depends mainly on three factors:

- The level of cooperation and communication. The introduction of the SFD optimiser has a number of negative effects that were described in the first paragraph of this chapter; less steady state operations, smaller margins for compensation, shared responsibility for diesel quality, and potential conflicts in HDS utilisation. All these negative effects can be prevented or dealt by good communication and cooperation between the production units and the economics and planning department. Especially the relation with RTC, which is responsible for the HDS's, becomes more important as both the flexible levels of desulphurisation and the HDS utilisation concern RTC. Given the fact that the SFD optimiser also includes the deactivation costs of RTC, the tool contributes to the relation between two actors. Maybe once a month a meeting between RTC and REP can be arranged to discuss the HDS utilisation schedules and evaluate the issues related to the flexible levels of desulphurisation. The issues with other production units can be addressed during the daily (4 PM) meeting with REP and production units. In case of upsets the production unit involved should call the economics and planning department, which then searches for ways to minimise the loss of margin.
- Dynamics in the performance review and assessment [de Bruijn, 2001]: not only the performance itself but also the process of achieving that performance should be considered (see §9.2). In case a production unit sacrifices some of its own performance to maximise the overall performance, some flexibility should be applied if this means that this production unit will not make its targets. The economics and planning department is best equipped to judge if a production unit contributes to the overall performance, as they are well-informed about the daily operations. Besides, often it is the economics and planning department that requires production units to cooperate and make sacrifices. This (unofficial) hierarchal power the main instrument the economics and planning department has, but an improvement can be made when another instrument is given to REP. An instrument to compensate production units in case they (have to) make sacrifices. Imagine a disruption in the Hydro Cracking Unit, resulting in a sulphur rich gas oil effluent. To minimise the loss of income REP asks RTC to desulphurise the light gas oil more, to compensate for the high sulphur content in the HCU gas oil. In this situation RTC sacrifices some of its individual performance (higher deactivation costs) to maximise the site-wide performance. At the end of the year RTC has to account for its performance. If this is below target, the assessor should be reasonable and also consider the sacrifices RTC has done. In this case REP should speak in favour of RTC. A practical implementation of the dynamic assessment is that every time a production unit sacrifices some of the individual performance REP provides them of a *pronouncement of contribution to maximisation of the site-wide performance*. At the end of the year, during the assessment these pronouncements should be considered. To increase the incentive to cooperate and to maximise site-wide performance the number of pronouncement can be made a performance indicator for the production units.

› The degree to which the SFD optimiser is kept up to date and is adjusted to the process conditions. This is a practical success factor that mostly depends on the design and documentation of the SFD optimiser. In chapter 8 the SFD optimiser and its features were discussed. As shown there, the utmost is done to assure user-friendliness and maintainability. It is up to the users if the decision support tool is applied. As already discussed in paragraph 8.3 the student will stay for some more weeks to assure that this requirement is satisfied and hence the chance on a successful incorporation of the SFD optimiser is assured.

If these three factors are safeguarded the chance that the complete potential gains (see §8.2) are realised is maximised.

10 Conclusions and recommendations

This chapter summons the conclusions from the research project described in the previous chapters. Also recommendations are done for, among others, further research.

10.1 Conclusions

The sulphur free diesel (SFD) optimiser is an off-line decision support tool that maximises the economics performance related to the sulphur free diesel production of Oil & Co Refinery B.V. It maximises the SFD optimiser margin, which is the total blend value of the diesel components minus the deactivation costs of the desulphurisation catalysts. The decision support tool is going to be used by the refinery's economics and planning department once a week for the formation of the week schedule and in case of disruptions in the diesel production process. Conclusions that can be drawn on basis of the research described in this report relate to the optimiser itself on the one side, and on the other side relate to the organisational environment in which the SFD optimiser is implemented.

Conclusions regarding the SFD optimiser are:

› It consists of a static, continuous, non linear optimisation problem with non linear constraints and is a relatively small optimisation problem.
› It is solved employing the Generalised Reduced Gradient method and is implemented in the GRG2 code, in Microsoft Excel.

Conclusions regarding the outcome of the SFD optimiser are:

› Desulphurisation in HDS/3 is more expensive than in HDS/2; and desulphurisation in HDS/2 is more expensive than in HDS/1.
› Decreasing the quality margin on sulphur leads to significant gains.
› Additional margin due to the SFD optimiser varies between 100 and 300 thousand US Dollar a week,[1] depending on diesel components' properties and the maximal desulphurisation depth. This monetary gain corresponds to 6.3 $c/bbl, which is one eighth of the 2007 ambition of the Global Margin Improvement program. It should be noted that if value differentials of diesel components drop, also this gain decreases.
› Non monetary gains are improved decision-making and a contribution to site-wide objectives and the goals of the economics and planning department and production units.
› Implementation is designed; no implementation difficulties are foreseen.
› The SFD optimiser satisfies all model requirements, like functionality, reliability, user-friendliness, value adding, etc.

General conclusions regarding the organisational environment of the SFD optimiser are:

› There are five main actors involved in the SFD production: the economics and planning department (REP), and the production units responsible for the desulphurisation of kerosene (RUD), the desulphurisation of light gas oil (RTC), the production of the HCU gas oil (RCP) and the blending (RBL).
› The objectives of the production units are related to the key performance indicators: Health, Safety and Environment; operation costs and operational availability. Their goal is to realise the targets set on these indicators at the end of the year.
› The objectives of the economics and planning department correspond mainly with the site-wide objectives; one of their main objectives is maximisation of the hydrocarbon margin.
› Once a week the economics and planning department formulates the week schedule and communicates this to the production units. The relation between the economics

[1] For calculations of this estimate the prices at the end of 2004 were used.

and planning department and the production units can be considered a mixture of hierarchal power (by means of the week schedule) and cooperation (as all actors are mutually dependent for performance achievement).

› In case of process disruptions, the production unit involved solves the technical problem and the economics and planning department searches, in consultation with the production units, ways to minimise the loss of margin.
› The structure of these actors can be best described as a professional network in which the production units can be seen as divisions. The production units are quasi-autonomous and have their own objectives. At the same time they depend on each other and the economics and planning department. The latter is responsible for the coordination between production units.
› To be successful decision support tools should combine the cost-focus of the production units and the margin-focus of the economics and planning department.

Regarding the implementation of the SFD optimiser in Oil & Co Refinery the following can be concluded:

› The SFD optimiser combines the perspectives of the production units and the economics and planning department and hence contributes to a better relation between them. It may contribute to the level and quality of communication and cooperation.
› The SFD optimiser contributes to the site-wide objective of maximising profits.
› The SFD optimiser contributes to the realisation of the objectives of the economics and planning department of minimal quality give away, optimal decision support and good communication.
› The quality give away is minimised as the optimal solution the SFD optimiser generates, often is constrained on two properties.
› The effect of the SFD optimiser's advices and the catalyst run length of the HDS's and thus indirectly HDS operational availability is ambiguous.
› The level of communication and cooperation between the production units and the economics and planning department become more important. The SFD optimiser leads to less steady state operations, smaller margins for compensation of process disruptions, shared responsibility for the diesel quality, and potential conflicts in the HDS utilisation. This imposes a communicational challenge. This challenge could be dealt with by introduction of a regular meeting of the economics and planning department with the production units which are most affected by the SFD optimiser and reflect on the achieved results.
› Not only the actor performance itself but also the way this performance is achieved should be considered. A kind of flexibility should be built in the performance assessment system that takes into consideration the sacrifices some production units make to maximise the site-wide performance. The economics and planning department should be given tools to create such a flexibility.

Final conclusion is that the SFD optimiser fulfils the research goal of developing a decision support tool that can be successfully implemented in the organisation.

10.2 Recommendations

The research resulted in a number of recommendations:

› Keep the SFD optimiser up to date to guarantee its life span and functionality.
› Investigate the opportunities to reduce the quality margin on sulphur content and the consequences of such a reduction. Part of this research should be focussed on the option to calibrate the quality measurement instruments more often.
› Examine to what extent it is rewarding to install a H_2S removal system on HDS/3.

- Perform a BUST (Bottom Up Stock Target) study to examine if the current tank capacity is sufficient to temporarily store diesel components in case of disruptions. If for instance the unit with the lowest sulphur content has an upset, downgrading of diesel components can be prevented by temporarily storing that product stream.
- Study the effect of the flexible levels of desulphurisation of HDS/1, HDS/2 and HDS/3 on catalyst run length. The impact of the SFD optimiser on the deactivation costs and the run length of the HDS catalysts has two opposite effects: one the one side the optimiser implies more flexible levels of desulphurisation and thus more flexible reactor temperatures in the HDS's. Also the lower temperature limit is lowered, as this increases the capability to compensate upsets. Expected is that this flexibility enlarges the catalysts deactivation and thus raises the deactivation costs. On the other side the optimiser adjust the level of desulphurisation of the light gas oil to the sulphur content of the HCU gas oil. Expected is that most of the time during the four year run length of the HCU catalyst, the advised level of desulphurisation in the HDS's is above the reference value of 7 ppm (remember §8.2). This suggests that the run length of the HDS catalysts is expanded, thus lower deactivation costs. Ambiguous is which of these two effects dominates.
- This project showed that significant gains can be realised by process optimisation. Maybe other processes are also suitable for process optimisation. For instance the hydrogen production and network is such a process.
- Examine to what extent the functionality of the decision support tool increases if the deactivation costs of HDS/4 and the HCU are included (directly). Now the deactivation costs of HDS/4 are embedded in the value of Des-Kero in the diesel blend, but these costs can also be included directly in the SFD optimiser, making also the level of desulphurisation on the HDS/4 flexible. The same holds for the HCU. Currently the HCU is not included in the model as the main process taking place in the unit is denitrification rather than desulphurisation. What would be the result if these units are included?
- Investigate the added value of a dynamic optimisation model. The SFD optimiser is a static optimiser, time dependent aspects, like deactivation mechanisms and stocks were not included. These aspects could be included in a dynamic optimisation model. Relating to the previous recommendation the deactivation of all HDS's and the HCU could be included in the optimisation. The added value of this inclusion should be investigated.
- Probe added value of an online SFD optimiser that regulates continuously the level of desulphurisation in the HDS's. See Appendix 11 for a sketch of such an online optimiser.
- Prevent downgrading of Des-Kero. In case sulphur content of Des-Kero is higher than 7 ppm, this can and should be compensated by extra desulphurisation of LGO.
- Look at the opportunities and likeliness that the T95 specification for diesel is lowered. A tightening of this specification would reduce the give away on T95.
- Teach the potential users of the SFD optimiser how to employ the SFD optimiser.
- Compare the advices generated with the SFD optimiser with the actual data (when SFD production has started.
- Recalculate the monetary gains described in paragraph 8.2 for the long term steering values. These values represent the expectations of future prices.

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Interviews

(Names are not given for privacy reasons)

- RTC: technologists, QMI specialist, process controllers (HDS SMOC's)
- RUD: technologists
- RFC: financial controllers
- RCP: technologist
- RHSEQ: performance assessment system designer
- RPC: SMOC specialists
- RBL: technologist
- REP: schedulers, economist, basic data manager
- RT: long term planner, investment projects
- TUD: academic staff

Appendices

Appendix 1. Organisation chart OCR

Not attached because of confidentiality reasons.

Appendix 2. RBL AGO blender

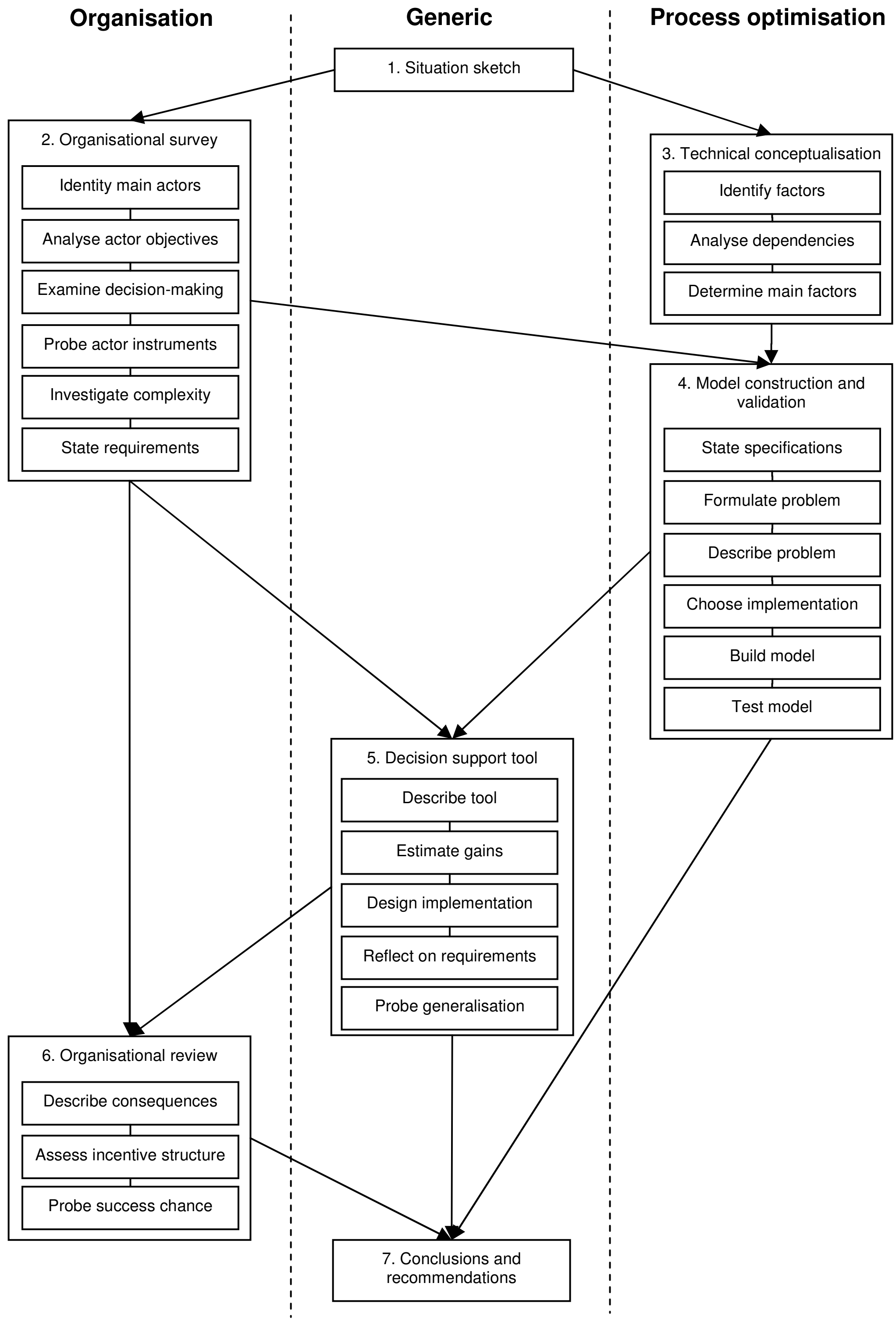
Not attached because of confidentiality reasons.

Appendix 3. Super Multivariate Optimising Controllers HDS's

Not attached because of confidentiality reasons.

Appendix 4 Research approach

To answer the research questions introduced in paragraph 3.3 a research approach [Van Meel, 1994] is formulated, consisting of seven steps. The steps concern three fields: the generic part of the research, the part of the research that focuses on the organisational aspects and the part that deals with the process optimisation.



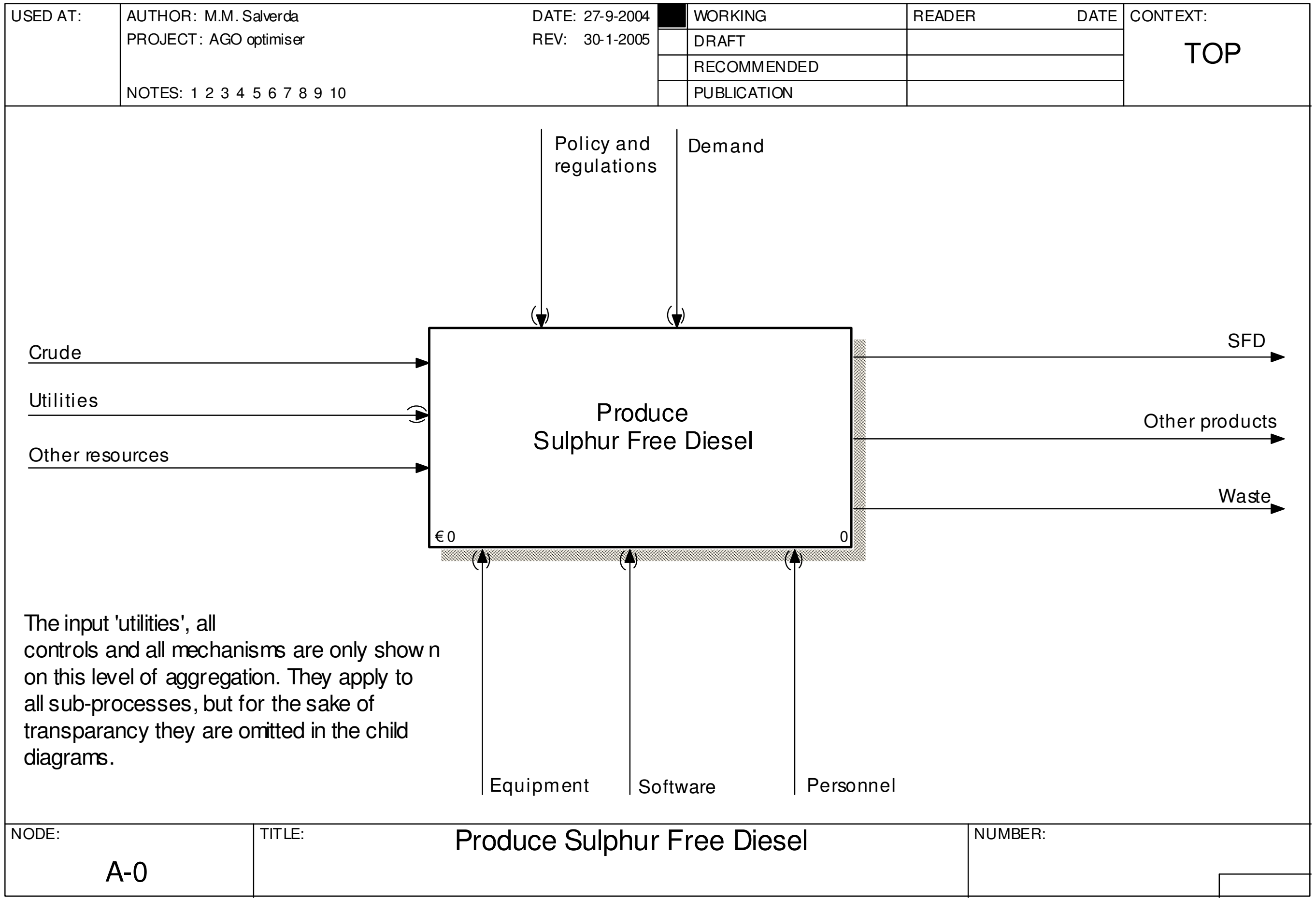
The figure above consists of seven steps that relate to the seven research questions introduced in Chapter 3. Below these steps are explained:

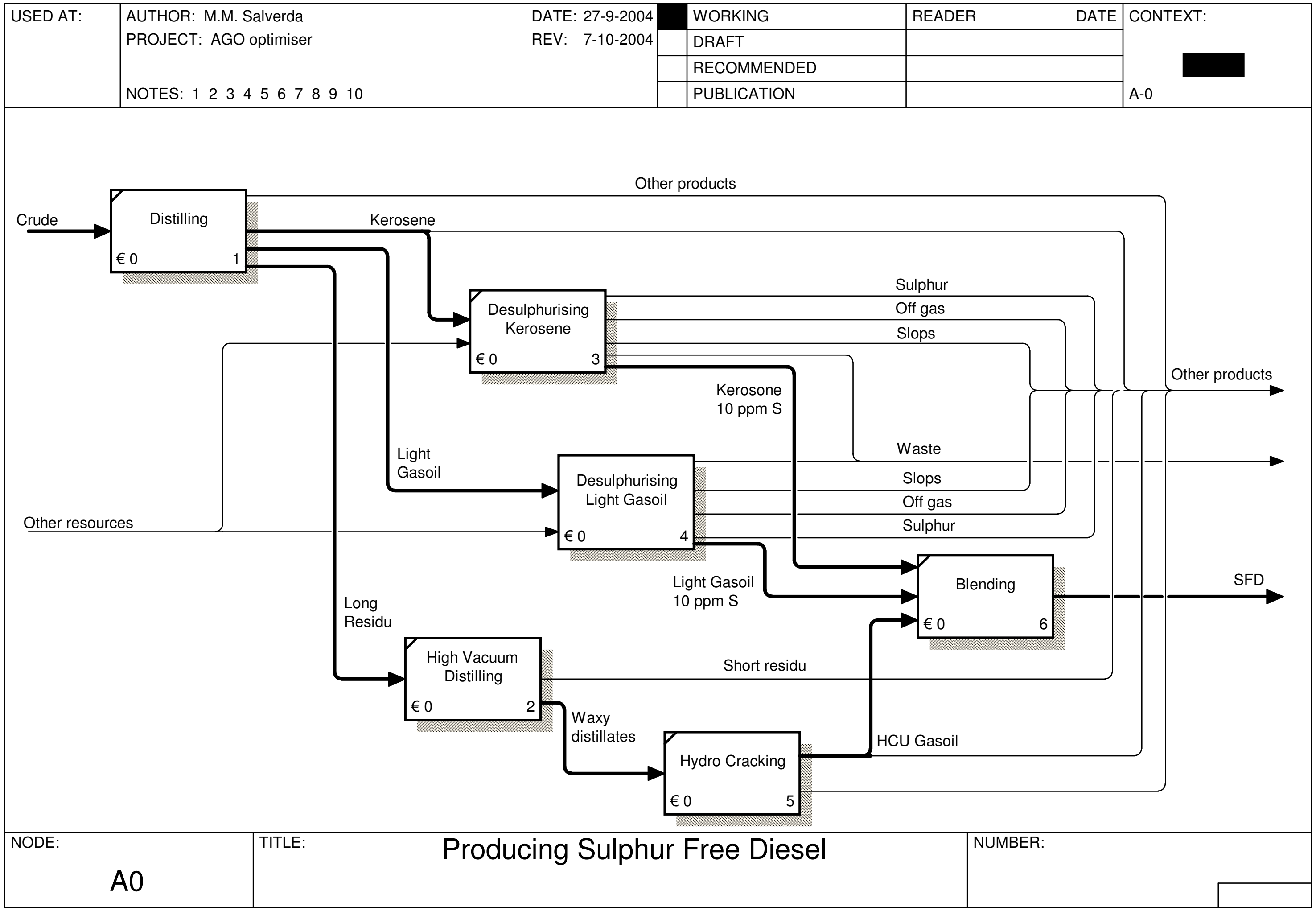
1. Situation sketch (research question 1): reason for introduction of sulphur free diesel, refinery basics, refinery organisation, current and future diesel production, future challenges and need of decision support tool.
2. Organisational survey (research question 2): actor analysis, objective trees, description of decision-making processes, steering instruments, organisational complexity, and requirements for a decision support tool.
3. Technical conceptualisation (research question 3):
   A basic understanding of the system was obtained during the first step, but this step conceptualised the technical problem, by reducing the technical complexity. This step consists of three methods:
   a. Analysing the processes to produce diesel is supported by an Integration Definition (IDEF) method[1]. IDEF is a standard to model the activities of an organization or system [www.idef.com; www.kbsi.com;].
   b. Identifying the relevant factors is done using the List Extension Method
   c. Determining qualitative dependencies between factors applying Causal Relation Diagrams.

   For these steps literature and the knowledge of Oil & Co's staff is going to be used.
4. Model construction and validation (research question 4):
   This step consists of activities:
   a. State model purpose and specifications: the intended result of the system model and its functional and non-functional requirements.
   b. Formulation of the optimisation problem: to determine if all relevant factors are included in the model. Also insight is gained in the data needed for optimisation
   c. Describe the problem: what is the size of the optimisation problem and what kind of problem is it?
   d. Choose implementation: what algorithms are suitable for this kind of problem and how should it be implemented?
   e. Build model: the actual construction of the optimisation model.
   f. Test model: the model needs to be tested for validity, sensitivity, consistency and usefulness.
5. Decision support tool (research question 5):
   a. Describe tool: who is going to use the tool, how should it be used and how does it look like?
   b. Examine gains: the monetary and non-monetary gains that are realised by the SFD optimiser.
   c. Design Implementation: formulate a plan of how the SFD optimiser should be implemented.
   d. Reflect on requirements: to which extent satisfies the SFD optimiser the model requirement introduced in §6.1.
   e. Probe generalisation: can the SFD optimiser be used in other situations?
6. Organisational review (research question 6):
   a. Describe the consequences of the SFD optimiser for operations, actor objectives, decision-making, cultural difference and future challenges.
   b. Assess incentive structure: reflection of the performance assessment.
   c. Probe success chance: analyse the chance of a successful incorporation of the SFD optimiser.
7. Conclusions and recommendations (research questions 7)
8. Literature survey: Literature is consulted during the whole project. Subjects are mainly theories about sulphur free diesel, catalyst deactivation, optimisation and organisations, performance assessment.

[1] Which was derived from the well-established Structured Analysis and Design Technique (SADT).

Appendix 5 IDEF0

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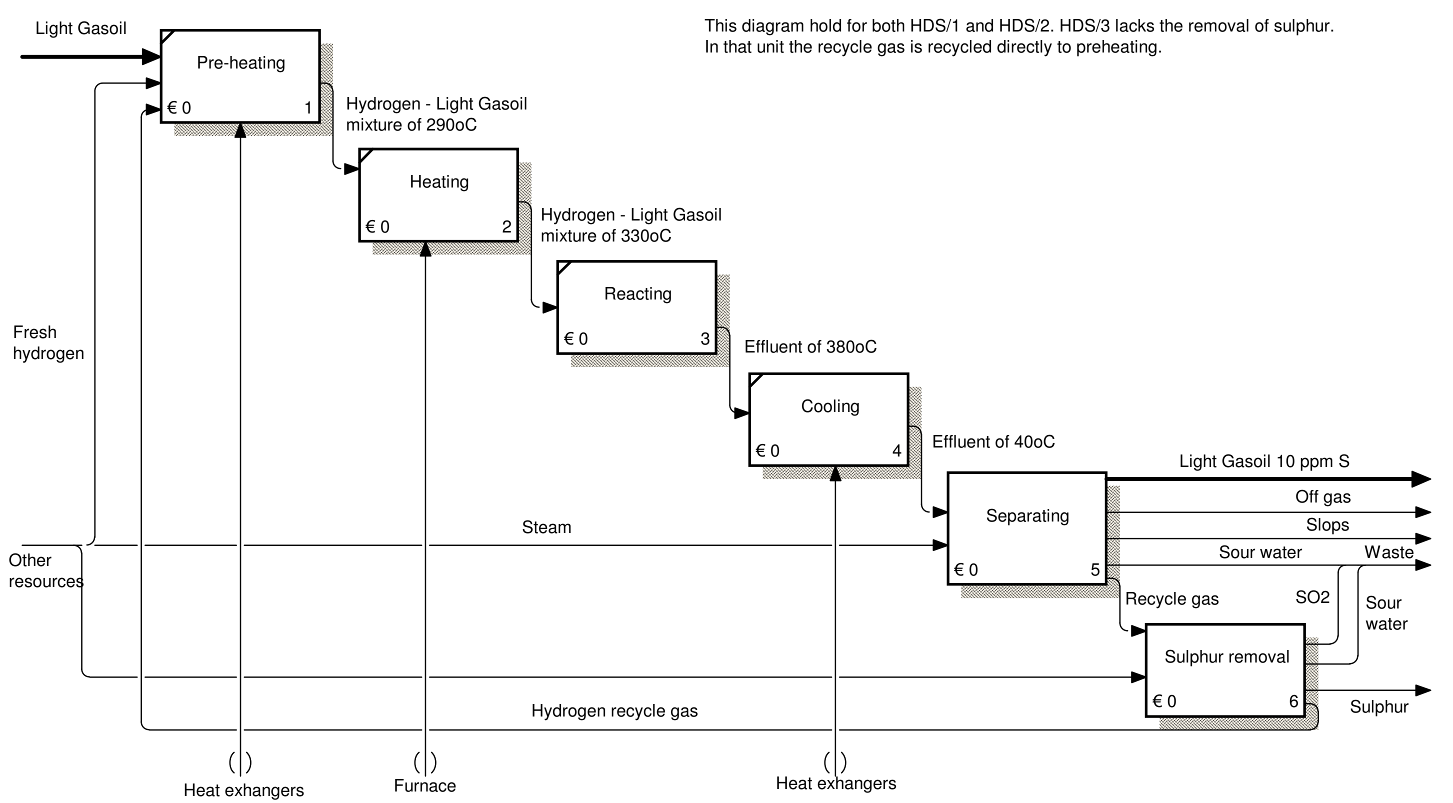

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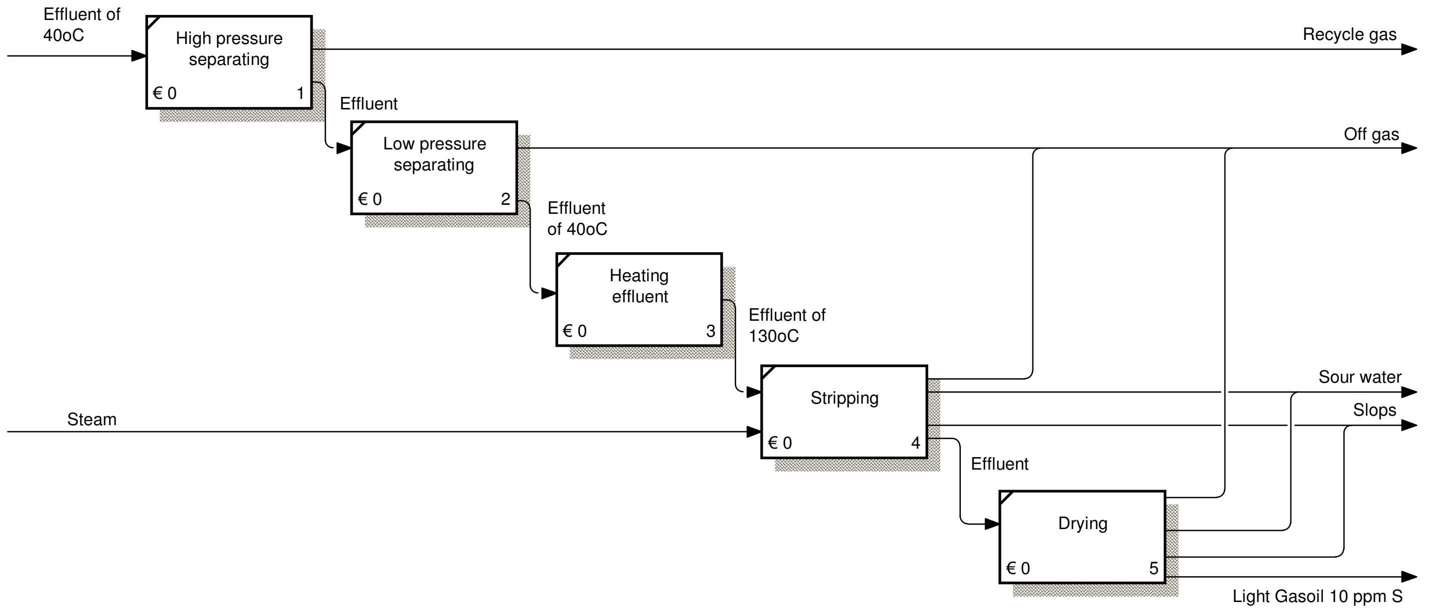
	PROJECT: AGO optimiser	REV: 7-10-2004		DRAFT			
				RECOMMENDED			
	NOTES: 1 2 3 4 5 6 7 8 9 10			PUBLICATION			A4

This diagram hold for HDS/1, HDS/2 and HDS/3, except for one difference. In HDS/1 and HDS/2 the recycle gas is lead trhough the DIPA system where H2S is removed. This results in a purer hydrogen stream in the HDS-reactor, thus increasing the hydrogen partial pressure. HDS/3 lacks the removal of sulphur. In that unit the recycle gas goes straight to the pre-heating after high pressure separation (see A4 diagram). To summarise, recycle gas in HDS/3 is polluted to a higher extent with H2S than HDS/1 and HDS/2.



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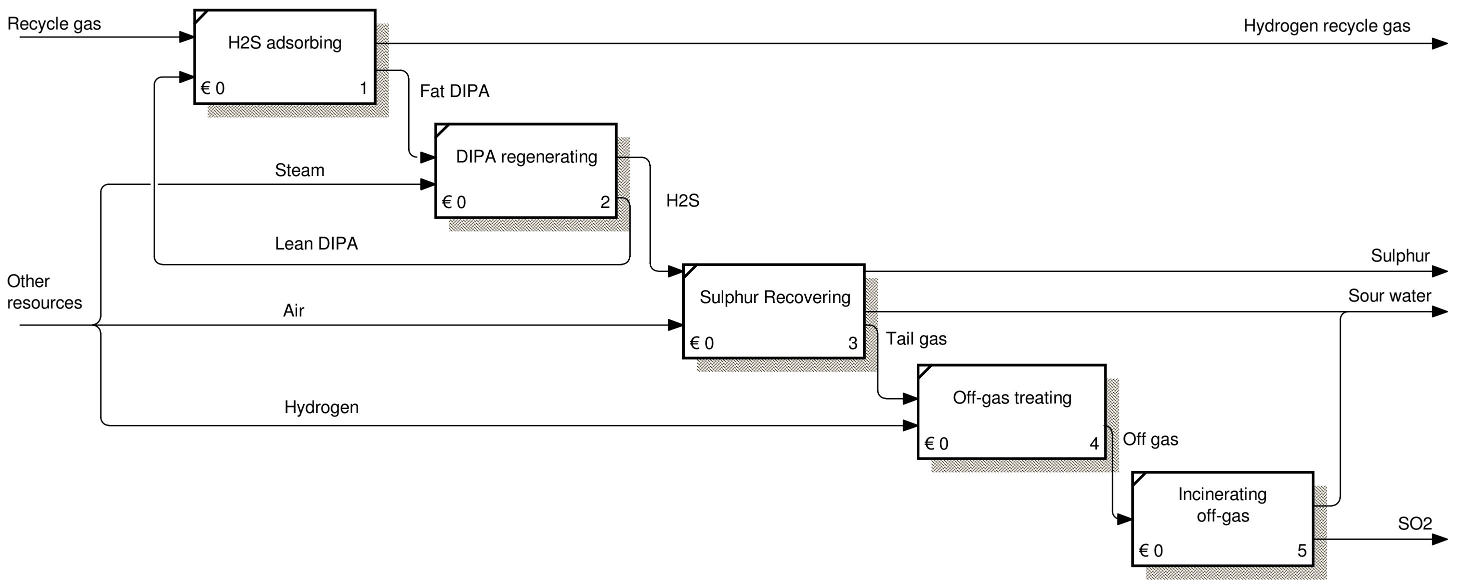
				RECOMMENDED			
	NOTES: 1 2 3 4 5 6 7 8 9 10			PUBLICATION			A4

This diagram hold for both HDS/1 and HDS/2. HDS/3 lacks the removal of sulphur. In that unit the recycle gas goes straight to the pre-heating after separation (see A4 diagram)..



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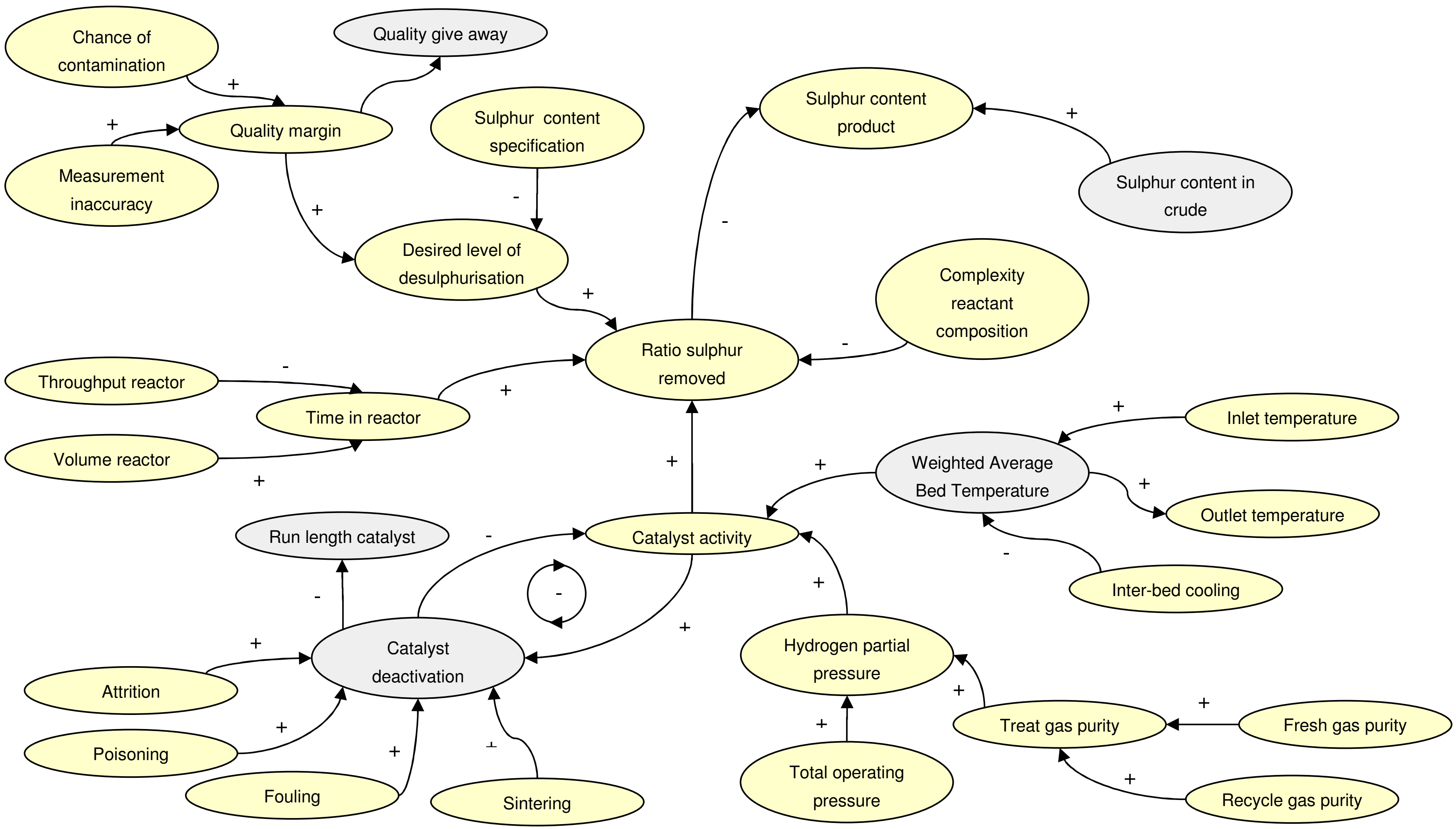
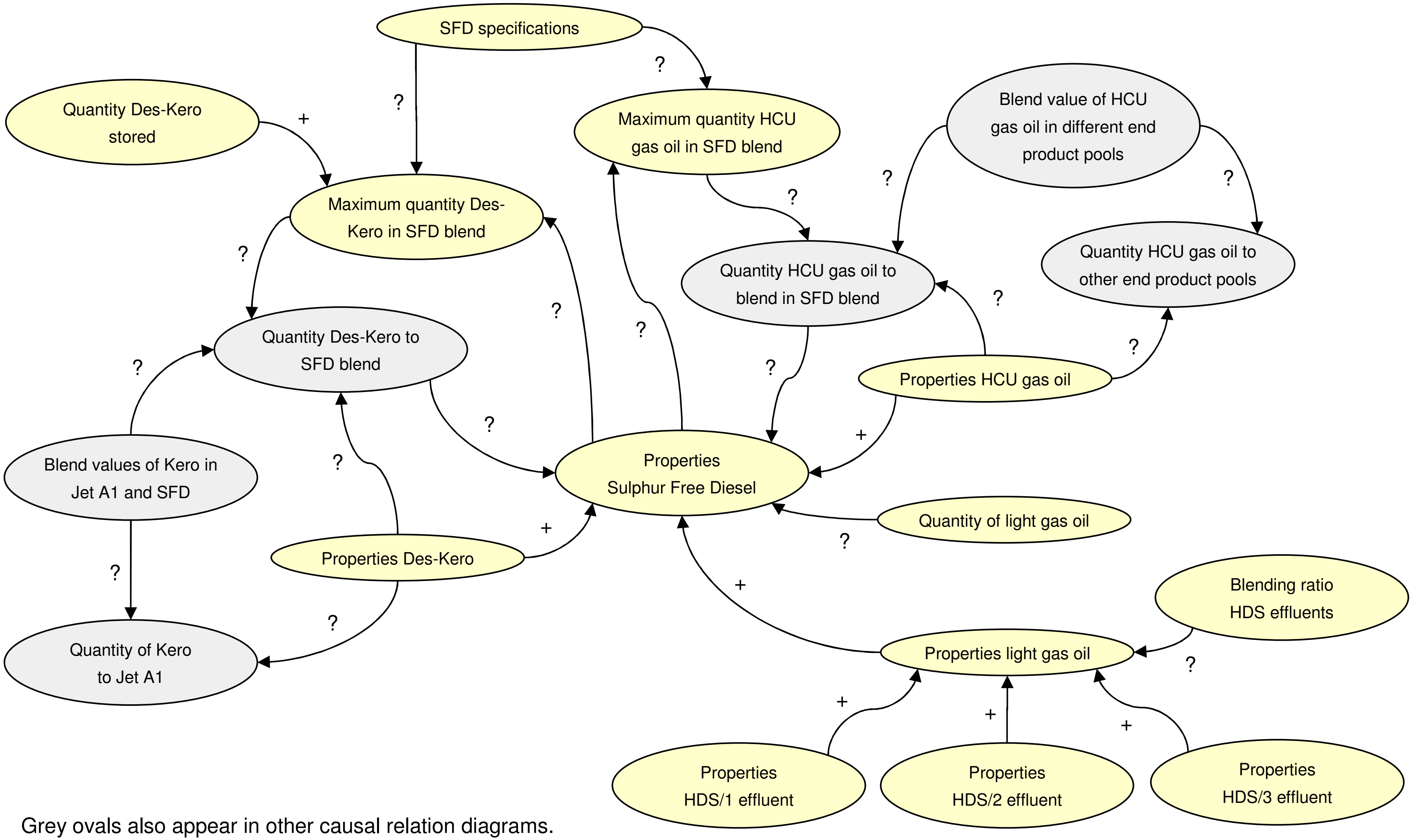
Appendix 6 Causal Relation Diagrams

Desulphurisation causal relation diagram



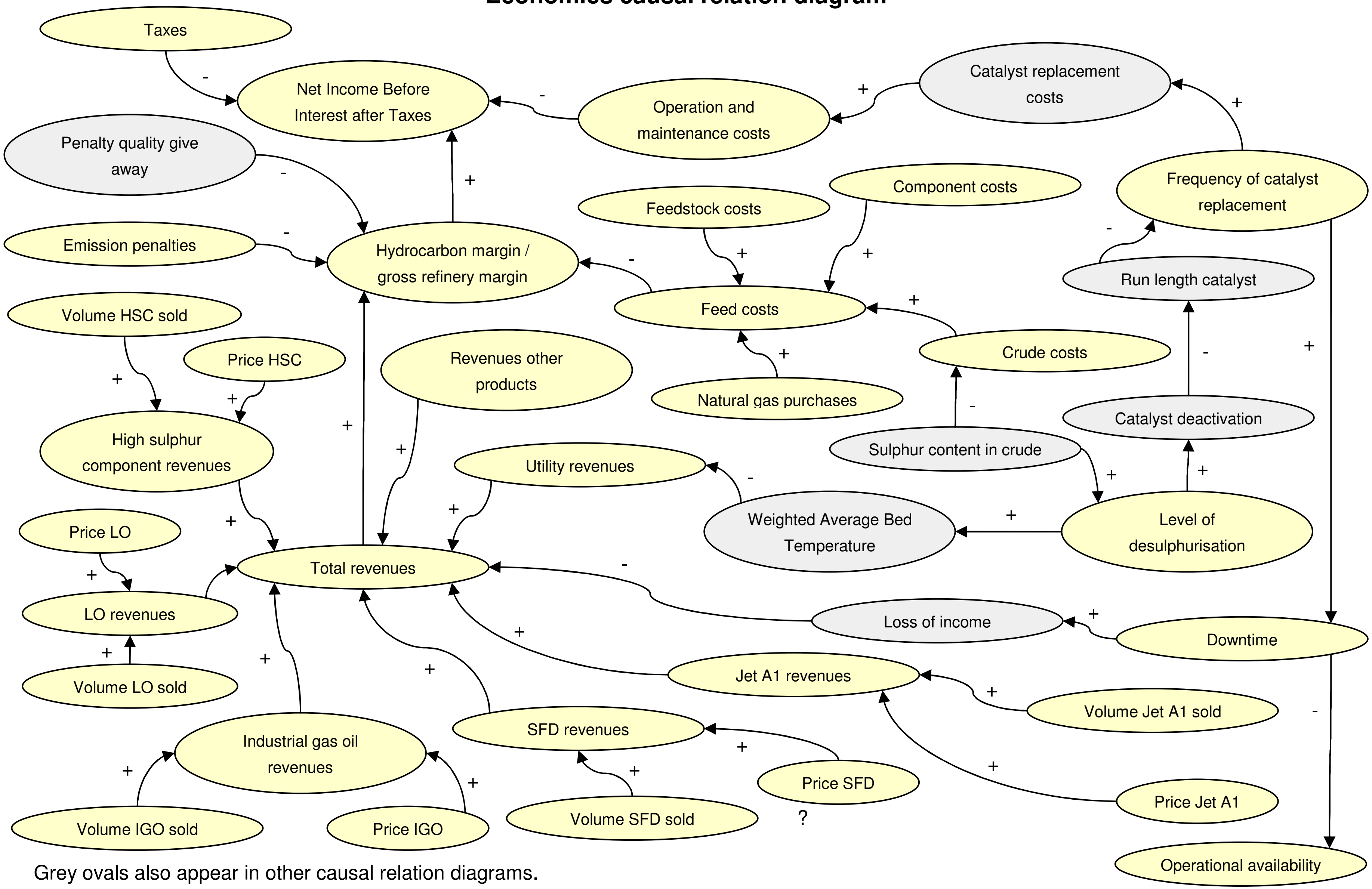
Grey ovals also appear in other causal relation diagrams.

Blending causal relation diagram



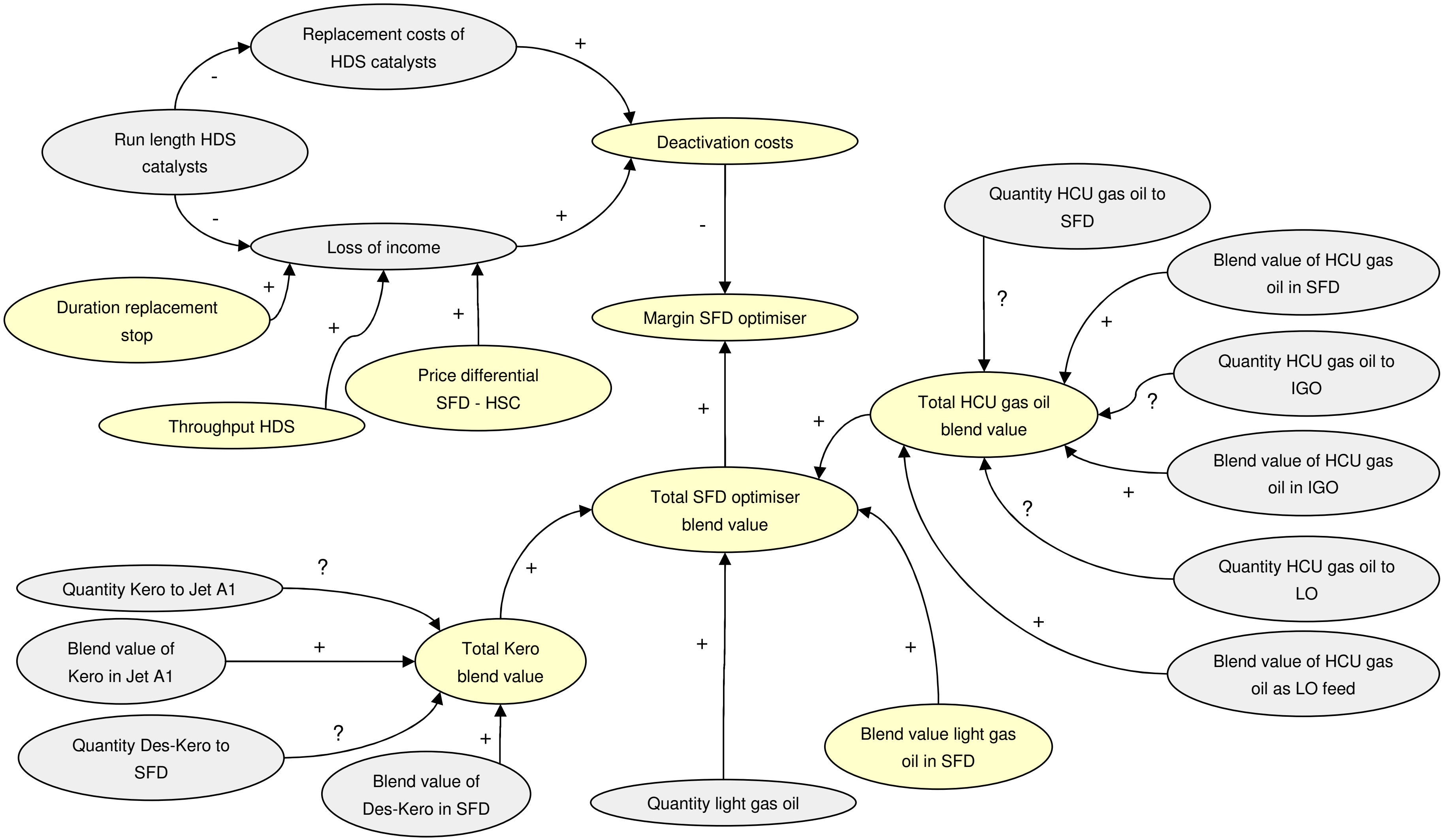
Grey ovals also appear in other causal relation diagrams.

Economics causal relation diagram



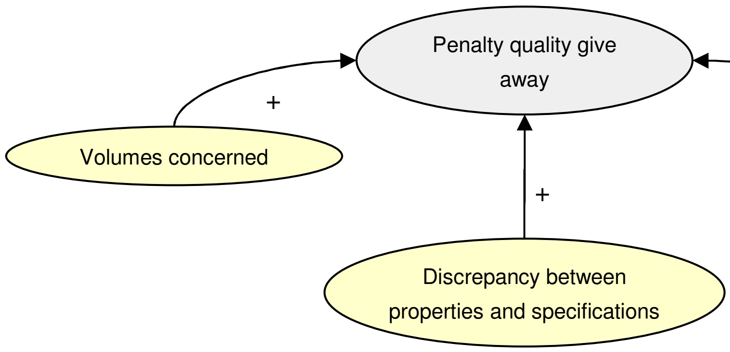
Grey ovals also appear in other causal relation diagrams.

Margin SFD optimiser causal relation diagram



Grey ovals also appear in other causal relation diagrams.

Quality give away causal relation diagram



Appendix 7 Impact desulphurisation on run length HDS catalysts

Not attached because of confidentiality reasons.

Appendix 8 Sensitivity analysis

Not attached because of confidentiality reasons.

Appendix 9 Designed experiment

Not attached because of confidentiality reasons.

Appendix 10 SFD optimiser worksheets

Not attached because of confidentiality reasons.

Appendix 11 Online optimiser

Not attached because of confidentiality reasons.