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Development of the Generic Dynamic Discounted Cash Flow Analysis Tool for Investment in the GasMat Park

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Abstract

The objective of this thesis is to design a composite investment valuation approach for GasMat research project. It includes the development of the generic interactive tool for analysis of investment and cash flows of a firm in the steel process industry. The developed tool is based on principles of modeling Cash Flows, Net Present Value, Black-Schole-Merton Real Option model, etc. In fact, the designed Generic Dynamic Discounted Cash Flow Analysis tool is able to assist in carrying out either positive or negative investment decision upon each and every Plant in the GasMat Park. Such a decision is subject to sufficient rate of return on investment under exogenous changeable business environment throughout entire project horizon. A case study of investment into hypothetic GasMat Steel Plant is executed.

Keywords: Steel Industry, Clusters, Network Flows, Investment Planning, Discounted Cash Flow Analysis, Net Present Value, Black-Schole-Merton Real Option

Preface

The research behind this thesis is the final part of the informative and enventful two-year study program at Molde University College. It is presented to the Faculty of Economics of the Molde University college regarding fullfillment of the requirements for the Degree of Master of Science in Logistics-

My deepest gratitude goes first and foremost to my supervisor Professor Irina Gribkovskaia for the support, guidance and constant encouragement upon the time-consuming and challenging process of writing the master's thesis. I also benefited a lot from regular meetings with her. Long fruitfull discussions of research issues, findings and model development improved significantly the quality of the work.

Secondly, I wish to thank GasMat project team represented by Kjetil Midthun, Matthias Hofmann and Thor Bjørkvoll at SINTEF, Applied Economics and Operations research for the oportunity to contribute to the real industrial R&D project, for the constant help and providing the requested materials, such as GasMat State of the Art Report and the prototype of the operational model.

Contents

1 Introduction

1.1 Motivation and background

During the academic year 2007-2008 I followed the course in Mathematical modeling in Logistics here at Molde University College. The course was lectured by Professor Irina Gribkovskaia. In my personal opinion, this particular course improved my skills in mathematical formulation of business cases. It played an introductory role into computer programming by studying an AMPL, a mathematical programming language. Eventually, it allowed me to take more advanced courses in combinatorial optimization.

In the middle of the second year of my MSc in Logistics I chose Professor Irina Gribkovskaia as my thesis supervisor. She offered me to participate in ongoing Gas-to-Material (GasMat) research project with respect to economic modeling and analysis of investment in the industrial cluster. The project is being run by colleagues of her Kjetil Midthun, Matthias Hofmann and Thor Bjørkvoll at SINTEF, Applied Economics and Operations research. Together with two other students I attended an introductory lecture upon the project at SINTEF Technology and Society in Trondheim, where I confirmed my decision to work on investment analysis of industrial facilities in the GasMat project.

With my Bachelor Degree in Economics, personal interest in investment theory and gained skills in mathematical optimization at Molde University College, it was a good opportunity for the master student to make a contribution in research of a real industry case.

1.2 Structure of the thesis

The thesis is organized as follows. In the Section 2, the description of the problem and an overview of suggested investment analysis solution is shown, including the role of developed Generic Dynamic Discounted Cash Flow Analysis (DDCFA) tool. The GasMat project is written up in Subsection 2.1 and Appendix B.

The conducted problem related literature research is executed in the Section 3. It focuses on the industrial parks in the steel industry from the point of mathematical programming and economic modeling of operations. Section 3 also presents range of valuation techniques for industrial investment, and suitable methods of quantitative time series analysis.

Section 4 formulates mathematically the concept that is behind the developed DDCFA tool. Briefly, the model represents a typical business Cash Flow Statement with added investment metrics. The latter is formulated as a set of functional relations to be calculated in consecutive order. The Net Present Value metric and Black-Scholes criterion are revealed as objective functions. The integral elements of Cash Flow Analysis model, necessary definitions and assumptions are discussed here in detail.

The development and distinctive features of DDCFA tool are discussed in Section 5. In addition, several screenshots of graphical user interface demonstrate the modular architecture of the interactive computer program.

Section 6 presents the numerical findings for the application of the tool with hypothetic GasMat Steel Plant. Finally, Section 7 concludes on the work done, including contributions to GasMat Project. Suggestions for possible extensions of Generic DDCFA tool are given with respect to valuation of real investments.

1.3 Development framework

MS Excel 2007 spreadsheets have been used for modeling and testing of a Generic DDCFA Tool. The developed code and the graphical user interface (GUI) have been coded in Microsoft Visual Basic for Applications Version 6.5. The auxiliary software that has been used for presentation of the thesis work is listed below.

File version control system

An open source version control system Subversion Version 1.6.1 and TortoiseSVN client for windows environment prevented several cases of occurred files loss and data corruption during the work upon the thesis in spring 2009.

Xpress-IVE Version 1.19.01

Xpress-IVE is a complete visual development environment for Xpress-Mosel mathematical modeling and optimization under Windows. It incorporates a Mosel program editor Xpress-Mosel Version 2.4.0, compiler and solver engine Xpress-Optimizer Version 19.0.

LaTEX editor

TeXnixCenter Version 1.0 has been used as the primary LaTex editor for writing and converting this thesis in TEX and PDF formats correspondingly.

BibTEX reference manager

A freely distributed and BibTex format oriented reference manager JabRef Version 2.4.2 has been used for compiling references in this thesis.

Statistical Package

Regression analysis and time series price forecasting have been done by means of use statistical environment SPSS Version 15.0 and R Version 2.9.0. The latter is a free software environment for statistical computing and graphics.

2 Problem description

2.1 Description of GasMat project

The thesis topic was considered to have a strong focus on developing a generic analysis tool for investment in GasMat production facilities. The mission of GasMat project is to prove that there is a more efficient way of using extracted natural gas from Norwegian Continental Shelf reservoirs in domestic steel industry as opposed to conventional export of natural gas. It is simply converted into liquefied petroleum gas (LPG) and liquefied natural gas (LNG) at Natural Gas Processing Plant. Domestic consumption of natural gas by potential industrial plants in the GasMat Park will result in generating economic value added of production and exporting of the valuable Direct Reduced Iron and Hot Briquette Iron (i.e. DRI Plant), the range of steel products (i.e. Steel Plant), and by-products such as carbon (i.e. Carbon Black Plant), methanol (i.e. Methanol Plant).

The wealth maximization of GasMat Park depends on correct and timely investment decisions. Real investment decisions in processing industry like steel manufacturing help to identify how much funds should be raised for setting up the whole cluster and what plants should be invested into. A project like GasMat is concerned with significantly large investments in long-term tangible assets (plants, equipment) and intangible ones as new technology, patents. All these assets generate cash flows spreading over an economic life of a project. The cash flow stream is a core component of investment analysis.

Some variance in the GasMat design is expected during research and analysis phase of GasMat project. Sufficiency of supplies of raw materials, favorable input costs and output sale prices over investment period are among exogenous factors that bring uncertainty. Other factors of risk include production planning along with forecasting of a trend (growing, falling) in the steel market. Types and number of contingent plants for GasMat integrated park should be selected based on the results that are obtained from suggested composite modeling approach. In the end, the final design, which yields the maximal profit, will become a potential investment decision thoroughly examined and revealed to the potential shareholders of the GasMat Park. An initial design of a gas fired integrated steel park was suggested by Midthun et al. (2008). A deep overview of GasMat Park is available in Appendix B.

2.2 The purpose of the thesis

The ultimate goal is to develop the Generic Dynamic Discounted Cash Flow Analysis (DDCFA) tool for GasMat facilities. It will provide end-users a quantitative investment support in identifying the facilities that will generate maximal profit and return on investment within a finite planning horizon.

2.3 Modeling approach for investment in GasMat Park

Apart from technical economic and engineering analysis, the final design of industrial Steel Park significantly depends on investment appraisal of a project. The investment analysis of a project starts with identifying correct project category. Dayanada et al. (2002) highlights three types of projects: independent project, contingent project and mutually exclusives ones. So, an investment in GasMat as a set of jointly running plants should be considered as an independent investment project. If only a specific plant is being examined, the analysis shifts from acceptance or rejection not independent project, but contingent investment. The latter assumes a certain level of correlation between plants in the GasMat Park. For demonstration of suggested modeling approach, the investment in the Steel Plant was analyzed, since it is as a major profit generator in the GasMat Park.

In this thesis, the investment valuation is based on a suggested three-step approach to be executed in consecutive order. First, it is necessary to perform a time-series analysis of the exogenous parameters of the cluster or particular plant. It includes a regression analysis and forecasting of price and quantity series of each facility input parameters (e.g. DRI/HBI, steel scrap, kWh) and output parameters (e.g. steel) in the cluster during the planning horizon. The examples of forecasting techniques are autoregressive forecasting, moving averages, and autoregressive integrated moving averages, etc..

An additional economic feasibility study of market conditions, including Norwegian import substitution of potential GasMat products and export possibilities is useful for investment design in production capacities for the planning horizon. Avoiding excessive production capacities that bring about unnecessary capital outflows is subject to production modeling and application of methods described in Subsection 3.2.2, 3.2.3. Second, usage of developed GasMat mass-balance model for operation simulation generates the gross earnings stream of flows over the time horizon. The access for early version of computer optimization model was granted by SINTEF Project team. The GasMat mass balance model is concerned with optimizing and obtaining the maximal gross earnings or minimal operation costs of overall Park.

Third, analysis of cash flows and investment is performed with a developed Generic Dynamic Discounted Cash Flow Analysis (DDCFA) tool. It has been decided not to integrated it inside the mass balance production model presented discussed in Midthun et al. (2008), but rather to develop a separate investment model. The latter focuses on the return on investment (ROI) over the economic period life of plants in the cluster. It evaluates the expected cash flow stream from GasMat plant(s) under GasMat exogenous and endogenous factors.

The DDCFA tool is based on mathematical programming approach, capital budgeting and real option theory. The inputs for DDCFA model in this case are input cost flows from raw materials supplies (natural gas, iron ore, steel scrap, etc.), investment costs for building each plant, cost of operation flows and income flow from each plant. Outputs are discounted net cash flow stream, net present value, profitability indices and value of investment with timing option.

Usage of a DDCFA tool within a suggested three step valuation approach has several benefits. It provides a clear and straightforward structure of performing an economic analysis of a complex object, including parameter forecasting, operation simulation and valuation of investment. All three modules can be separately used for partial economic or investment analysis. The investment valuation techniques implemented in the DDCFA tool are discussed in the Section 3. The connection between modules is based on input-output relationship. Since a developed DDCFA tool is a generic and separate module, it can be also used for investment valuation of any investment with timing option.

3 Problem related literature research

3.1 Economic benefits and risks of the integrated steel park

GasMat industrial Park will become a complex industrial production system that combines existing Natural Gas Processing plant and Methanol plant with potential DRI plant, Power Plant and Steel plant and auxiliary production units. All facilities will be located at single point acting like consortium of Norwegian and Swedish companies. Pulling companies resources in order to set up a profitable and market oriented GasMat cluster requires a number of engineering and economic feasibility studies including valuation of investment in plants, cash flows and return on investment from GasMat project. This literature research aims to provide SINTEF researchers robust sources of quantitative methods, optimization models and industry examples of such investment analysis. In addition, the most popular practices are implemented in the developed generic DDCFA tool, which is described in Section 4.

The economic benefits and risks of plants involved into a cluster have been pointed out by Midthun et al. (2008). It was considered that an integrated cluster should be managed by the central planner in order to coordinate the market fitting production plans and achieve profitability of production facilities. The dependency on other companies and the risk of losing investments in shared specific infrastructure if some plants quit from the cluster are two main sources of risks.

Literature evidence on potential economic and environmental benefits or risks of eco-industrial parks (EIP), its impact on member firms and communities has been seen in Martin et al. (1996). The report became a step guide for planning, developing and managing an industrial park. It is based on the research of the case study regarding regulatory restrictions, standards of business practices, technological and environmental limits, sufficiency of economic benefits and scenario simulation. The linkage with this thesis can be seen in Table 1, where a criteria set of measuring EIP's profitability, investment return is presented. To determine the economic impact of EIP, Martin et al. (1996) compared several criteria (i.e. new members, shared infrastructure, etc.) of designed EIP's scenario (j) with the initial (i.e. base activities with minimal number of members) scenario ($j = 1$). In the following table, i denotes the index of inputs and outputs; x_i is positive number if it is an output and negative if it is an input; $\Delta\pi$ denotes the change in the net economic benefits (benefits minus costs).

Table 1: Criteria for Measuring the Economic Benefits of the EIP

Indicator	**Data Required for each scenario j**	**Method**
Change in annual profit (net benefit)	$p_{i,j}$ - input, output prices $x_{i,j}$ - input, output quantities I_j - annualized cost of capital investment to implement scenario j $F_j - F_1$ - lump-sum cost of capital to upgrade from scenario $j = 1$ to j r - interest rate (borrowing rate) to finance capital investments t - the term of the loan and expected project life of investment	$\Delta\pi_j = \left(\sum_{i=1}^{n} p_{i,j} x_{i,j} - \sum_{i=1}^{n} p_{i,1} x_{i,1} \right) - I_j$ $I_j = (F_j - F_1) / \left(\frac{1 - (1+r)^{-t}}{r} \right)$
Change in the annual cost of production per unit	$p_{i,j}$ - input prices $x_{i,j}$ - input requirement per unit Total Annualized costs: I_j - annualized investment cost, regulatory costs of hazardous material, transportation costs	$Change = \frac{TotalAnnualizedCosts}{Output}$
Return on investment (ROI)	$\Delta\pi_{i+1}$ - net benefit of investment in the year t after the start in year i r - discount rate to finance borrowed investment capital t - the term of investment life	$\sum_{t=0}^{n} \frac{\Delta\pi_{i+1}}{(1+r)^t} = 0$
Payback period	FCF_i - operating cash flow less capital outflows in period i	$PB = \min_{k=1,\ldots,n} \left\{ k : \sum_{i=0}^{k} \frac{FCF_i}{(1+r)^i} \geq 0, \infty \right\}$

The ROI can be interpreted as the rate of discount r that reduces the net present value (NPV) of the $\Delta\pi$ flow over n years from a project. It is a minimal possible rate to return occurred investment costs from project over its life period. The ROI or the internal rate of return (IRR) is used to compare expected returns on alternative EIP's investment scenario in order to choose the best (i.e. with the highest ROI) regarding same investment period and positive value of NPV. The payback period is the length of the term (i.e. years) to recover the full cost of investment. Both indicators can be relaxed (i.e. longer payback period is taken into account) if some of the data required for calculation cannot be clearly quantified. Benefits of communities author measured with value added by workforce employed, tax revenues and etc..

3.2 Mathematical programming in the steel industry

A great survey of steel making operations in Integrated Steel Plants with respect to mathematical programming applications is presented in Dutta and Fourer (2001). Several classes of problems have been thoroughly examined. They are national steel industry production planning, product-mix optimization, blending problems, scheduling, distribution, and inventory and cutting stock optimization. The majority of references are based on case studies from different countries published between 1958 and 1997.

3.2.1 Economic evaluation of modeling steel production processes

Pielet and Tsvik (1996) developed the Mass and Energy Balance Economic model for DRI production and Steel manufacturing for LNM Group. It operates direct reduced iron (DRI) plant and steel plants with Electric Arc Furnaces (EAF), Blast Oxygen Furnaces (BOF) and Midrex modules. The author compares profitability of developed models to be either Production-limited or Sales-limited. The paper investigates effects of substitution inputs of Pig Iron for Pig-sub, which is a low cost scrap in steel making processes. Value-in-Use concept is introduced. It focuses on the maximum affordable price for replacement material without worsening profitability of particular plants. The author also provides a guide to economic optimization of overall LNM Group profitability. With respect to market conditions an increase in the profitability of the DRI facility is compensated by drop in profitability of the EAF facility. The paper neglects the importance of fixed costs and focuses on changes in variable costs. The concept of profit is opposed to contribution value. The latter is the difference between variable production cost and sales revenue. The paper gives evidence on input quantities, prices and unit production costs of plants.

Burgess et al. (1983) analyzed profitability of DRI plant based either on coal or natural gas processes, originally designed by the Midrex Corporation. The author pointed out that choice of technology was depended on actual DRI global price conditions, local raw material and energy costs for the chosen process. The study focused on sensitivity analysis in changes of plant capacity, capital cost and operation costs. In order to choose favorable DRI plant design, the author used simple yearly cash flow analysis. The model was used to compare economically available process designs. It was done by analyzing the yearly cash flows of a hypothetical DRI plant over the expected life of investment:

$$CF_i = (1 - t) * (R_i - E_i) + t * D_i - CI_i - WC_i \quad (1)$$

where: (CF_i) is a cash flow (in currency units) at the end of year i; (t) - taxation rate (fraction number); (R_i) - sales revenue (in currency units) at the end of year i ; (E_i) - expenditure to produce sales at the end of year i (in currency units); (D_i) - depreciation on plant and equipment in the year i; (CI) - capital expenditure in currency units; and (WC) - added working capital (in currency units) in the year i .

Another linear programming model for integrated production planning is presented in Chen and Wang (1997). The model belongs to a network flow problem class. The static (i.e. single time period) small-scale model controls raw material purchasing, semi-finished goods production and purchasing. Production and distribution of finished product during the current planning time period and allocation of limited capacities is in focus too. The purchasing of semi-finished product is intended to cover seasonal demand fluctuations and extra sales of finished product under favorable market conditions. The key measuring units for production planning are plant available production time and production rates. The model does not support multiperiod planning since product inventory constraints are not included. The author initially aimed to develop a onetime integrated planning model for a Canadian steel making company. The stockout situations are not modeled either. Typical raw material supply, capacity, production and demand constraints are incorporated. The objective function of the model is to maximize pre-tax total earnings of the central steel making plant as difference between total selling income and total cost. Inputs of the model are raw material and semi-finished purchasing costs, production and transportation costs, product throughput rates, customer demands, sales prices and plant capacities. Outputs are optimal production and distribution quantities of final product. Even though the model is static and simple, the existence of a central planner (i.e. central steel making plant) presents an interest for the production planning of the GasMat integrated steel cluster, and its investment appraisal.

Larsson (2004) suggested a process integration methodology for the integrated steel plant. Several mathematical models were developed with respect to modeling of steel making processes at each production stage. The models are based on mass balance concept and reflect different production technologies (i.e. coal and natural gas based). Savings in material cost, energy use and reductions in environmental emissions of steel production have been achieved. The study has been applied at Swedish steel mill SSAB Tunnplat AB. It also provides a number of robust sources for real input-output production process coefficients, material and energy use. Overall, the methodology is most suitable for engineering feasibility study and production planning rather than investment analysis of steel mill return on capital investments. Initially, the study had no interest in capital investments, equipment costs and cash flow analysis.

Kekkonen et al. (2006) suggested a methodology of comparison two conventional steel manufacturing processes. An initial process did not consider emissions handling, while the second process incorporated emissions capturing. The latter includes more complex process integration (i.e. yield enhancement in thermodynamics) within plant and between plants. It includes optimization of material use(i.e. minimization of waste production) and energy use within the production site. Process modification causes calculation of potentials as a difference in performance values between the existing and modified process. The comparison is based on a set of criteria that affects process design and efficiency of the investment. Economical numerical criteria examine profitability or contribution of the design. Capital costs, specific investment costs on equipment and infrastructure, and operation costs are analyzed with payback period time (PP), Net Present Value (NPV), etc. Non-numerical non-economical criteria include environmental aspects (i.e. gaseous wastes like carbon dioxide CO_2, sulfur dioxide SO_2, NO_x, etc.) and technological aspects (i.e. capacity, consumption of raw materials and energy, etc.). To perform above analysis Kekkonen et al. (2006) used data collected at Raahe Steel works, and Factor simulation program based on mass balance concept. This program was developed for "Iron and Steel MMX" 1999-2003 project at the University of Oulu, Laboratory of Process Metallurgy.

3.2.2 Investment modeling of production capacities as strategic planning

For the first time, Kendrick (1967) in his monograph "Programming Investment in the Process Industries: An approach to sectoral planning" presented a national investment planning model for the process industries. The model application aimed to optimize investment planning of capacities in the steel industry in Brazil in 1960s. Three models were developed. Small and large static (i.e. single period) linear programming models are variants of mixed production and transportation model. Three still mills and three markets were considered. Inputs are prices of raw materials, operations and shipments, market requirements. The model incorporates predetermined capacities of plants at a time period zero, input-output coefficients of production units, production costs. It uses assigned internal transportation (shipments) costs between plants and transportation costs from plants to markets, and expected profits on exports. Outputs are optimal product distributions. The small dynamic (i.e. multiperiod) mixed-integer version adds inventories and investment decision variables of when and where to add additional productive capacity. Thus, scheduling of investments in steel plants capacities has been considered as investment planning type problem. Even though the model is deterministic, it could work as of day if modern time series analysis is applied to reduce uncertainty. In fact, the author admitted that collecting real investment data, plant equipment costs as opposed to operation and transportation costs is often a subject to feasibility studies with limited access. Nevertheless, the author gives the evidence of industrial equipment costs, and correspondent references.

The methodology suggested in Kendrick (1967) was revised and generalized in the book "The planning of industrial Investment Programs" by Kendrick and Stoutjesdijk (1978). Limitations of the model such as its deterministic type, fixed demands and fixed price inputs were discussed. In Kendrick et al. (1984) the study of steel processing was supplemented with General Algebraic Modeling System (GAMS) code for two static and one dynamic model. The GAMS code is also available in Internet in GAMS (2009). Later the methodology was published in Kendrick et al. (1990) and Amman et al. (2006) as part of sectoral macroeconomics with a strong linkage to computable equilibrium and growth models.

The book by Dore (1977) suggested a model regarding dynamic optimization of investment. An investment planning model with known economies of scales in capacity investment and operation costs is suggested. The model deals with timing of plant capacity extension and reduction of imports. The application is confined to a single country. Zambian steel industry represented the case study. The author uses regression and time series data analysis for estimation of model parameters such as prices, economies of scale, production costs and demand projections. Sensitivity analysis used simple growth parameters for creating long-term price, production and import scenarios. The book also includes the flow chart of the algorithm for computing the model and a number of sources for parameter settings.

Modeling investment upgrades in existing plants and building of new Greenfield plants is studied in Schwarz (2003). The partial equilibrium model was built using linear programming approach. The model was developed for testing long term scenarios regarding capacity of facilities with change of technology over the time (i.e. modernization of plant). Assuming giving demands, objective function of the model focuses on minimization of total discounted costs. It is a function of a discount factor (σ_t) over discount rate (p), operating costs (OC_t) and capital costs (CC_t):

$$TC = \sum_t \sigma_t OC_t + \sum_t \sigma_t CC_t \rightarrow Min \tag{2}$$

$$\sigma_t = \frac{1}{(1+p)}, \forall t \in T \tag{3}$$

Thus, it is another evidence of applying discounting approach when modeling long-tem investment. The full model is available in Schwarz (2003). It considers mathematical formulation of aggregated operation costs, capital costs, market flows and foreign trade constraints, capacity constraints and non-negativity requirements.

A stochastic program linear model with simple recourse (SLPR) for strategic planning of investment and economies-of-scale in the Indian iron steel industry was developed by Anandalingam (1987). The paper addresses the uncertainty in demand and technological coefficients in the steel industry. It was assumed to be fixed in the previous studies, for example in Kendrick (1967), Kendrick et al. (1984) and etc. With known mean and variance and unknown distributions of the stochastic entities of the SLPR the author derives the solution algorithm by transforming the SLPR into deterministic semi-quadratic model. The model itself is of classical blending type with input-output constant coefficients to transform material inputs into product outputs. The model includes proportional by-product outputs, constraints equating inflows and outflows, energy and material requirements and etc. The transformed version of this model also includes investment equations for strategic planning of capacities. Although, the idea belongs to Kendrick et al. (1984), who applied piece-wise linearization in order to approximate investment cost function. The investment decision itself is about when in time and where in production system to add additional predetermined units of capacity. This coke processing model includes neither links with suppliers of raw materials (i.e. kWh, fine ore, and coking coal) nor transportations costs. The output sales (i.e. scrap, blooms and slabs produced from steel ingots) are not considered. Due to technological progress and high implementation cost, the process of direct reduction of iron was not considered at that moment.

3.2.3 Estimation of investment costs and economies of scale

According to Dore (1977) there are several methods of measuring economies of scale. They consider specific and/or complete investment costs of an industrial processing plant. The first approach suggests using a cost function:

$$C = bX^{\alpha} \tag{4}$$

where C is the capital costs; b - a constant; α - the scale coefficient; and X - the capacity of facility. The author argues that 58% of the estimates of α lie in the range of 0.50 to 0.79. The scale coefficient varies with the plant production process route. For example, Dore (1977) gives an evidence for the steel plant with integrated blast furnace basic oxygen system (BF-BOS) route. It is equal to $\alpha = 0.56$ for the range of capacity between 0.1 million metric ton (MT) for the UK. Similar empirical evidence is also provided in Kendrick et al. (1984).

Every plant in GasMat cluster has different production process routes. The empirical evidence on equipment and other specific investments for each plant is not always available for the public access. If this is the case, a piecemeal approach can provide some capital estimates regarding size of a plant. It suggests estimating the elasticity between the hypothetical highest and lowest plant sizes. The elasticity, α coefficient can be estimated as:

$$\alpha = \log(X_2/X_1)/\log(Y_2/Y_1) \tag{5}$$

where X_2 is the capital cost at the higher plant size; X_1 - the capital cost at the lower plant size; and Y_2, Y_1 are the upper and lower plant capacities correspondingly. Both methods can be used for modeling and estimating specific investment costs and potential size of facilities in GasMat production model suggested in Midthun et al. (2008). If incorporated, it will provide the basis for estimation of capital costs, which affect the production and yearly gross earnings. The gross earnings, investment and operation costs are inputs for dynamic discounted cash flow analysis (DDCFA) tool. Thus, it will also affect the estimation of return on investment of plants in the cluster.

3.2.4 Corporate planning and decision support system practices

A computerized corporate planning model has been described by Narchal (1988) and Kumar (1990). The model was developed to conduct simulation and sensitivity analysis of various scenarios of production output products and capacity planning in the integrated steel plant over several years on monthly basis. The author aimed to evaluate plant modernization and expansion incentives by means of reduction of capacity bottlenecks in the system. The integrated system dynamics feedback model of a production system modeled the flow of materials, labor and machines of existing capacity centers at every steel production stage (i.e. sinter plant, furnaces, melting shop, different mills, etc.). The simulation was carried out at Tata Iron and Steel Company. Like in many other articles the economic performance of the plant or corporate performance has been simulated with respect to profit, works cost and investment on return.

Optimization of scarce resources within production system and optimization of product-mix problem has been studied by Sinha et al. (1995) at Tata Steel, an Indian integrated steel plant. The developed mixed-integer linear programming model for production planning considers marketing constraints, optimal allocation of capacities of processors (i.e. production facilities), technological routes, etc. The dynamic model with interperiod inventory linkages as well as static version focuses on optimal distribution of power flow under fluctuating supplies and flow of materials, and by-products. It identifies optimal product-mix of finished and semifinished steel products regarding market conditions. Simple on/off decision rules and scenarios upon unloaded or idle production facilities were developed to deal with unstable power supplies. It was necessary to optimize fixed and variable power consumption (i.e. kWh). To measure economic benefits and to define best production strategy, profitability indicator, break-even prices and product yields are used. The author concludes that during the period of power deficit as constrained resource, contribution per kWh indicator should be used instead of contribution per ton. The mathematical formulation of the model is presented in the paper.

Singer and Donoso (2006) argue that strategic decision-making benefits from combining a linear programming (LP) production planning model and Activity Based Management. The dynamic LP model incorporates Activity Based Costing (ABS) approach, which considers a production system as a network of work centers connected by physical flows. Available resources are assigned to activities. Activity cost is estimated by prorating the actual use of resources in it. Its mathematical formulation is provided in the paper. Feasibility of production plans is modeled using typical linear constraints limiting flow and inventories such as maximum demand, throughput, blending, interperiod inventory linkages, maximum inventory constraint, and etc.. In their study, the authors refer to production planning model described in Chen and Wang (1997) and Dutta and Fourer (2001). The study was applied in a Chilean integrated steel company, while the model was implemented in a MS Excel spreadsheet using a Frontline system solver.

A decision support system (DSS) tool was described in Dutta and Fourer (2004). The tool is considered as a generalized multi-period optimization-driven DSS for processing industries. The paper describes the multi-period LP network-flow model of continuous steel production that was applied in an American steel plant. The model is implemented within the relational database and solved by linear programming XMP solver. Key modeling database components are materials, workcenters, activities, time periods and storage areas. The model's objective is to maximize the sum (nominal or discounted) over all periods of sales revenues less purchasing costs, costs of inventories and converting, operating activities costs at work centers and capacities used up at workcenters. The model is subject to constraints in material balances, workcenter hard/soft capacities, inventory capacities and bounds. Bounds on workcenter number of inputs, outputs and activities are introduced. Bounds on amounts of units bought, sold and inventoried treat equally any flow of raw material, intermediate of finished product in the model. Inputs, outputs, cost per product unit, yields, capacity restrictions and min/max production boundaries are analyzed regarding activities. There are different activities assigned to different workcenters, so the workcenter-activity ratio is introduced. The latter is a number of units of activity accommodated by one unit of workcenter's capacity. The full model formulation is provided in the paper. With respect to strategic and operation planning the model treats definition of time in a flexible way. A unit time in the multiperiod model can be scaled from a week to a month, quarter and year. Finally, the author point out the necessity of the discounting factor $(1+p)^{-t}$ and the interest rate p in the objective function for the cash flow in any period t. Rationally, a cash flow occurring in future period t should be discounted from the present period point of view. It is obvious that value of the money changes over the time.

3.3 Valuation techniques of industrial investment

In this subsection the most used and approved methods suitable for investment appraisal in the real industry are presented. All of them came from Finance theory and applications, particularly from Capital Budgeting theory and Real Option Valuation (ROV) theory. Strengths and weaknesses, deterministic and probabilistic behavior of methods as well as fuzzy techniques are discussed below. Some of these methods have been implemented in the DDCFA tool for the purpose of evaluating investments in GasMat plants. It is important to highlight that this thesis is focusing on methods of discounted cash flow analysis, and investment appraisal of a Greenfield (i.e. a new) plant rather than a plant expansion or a project replacement.

Capital Budgeting models

A great all-in-one introduction to Capital Budgeting theory is the book by Dayanada et al. (2002). It discusses quantitative techniques of forecasting time-series, deterministic and stochastic valuation techniques of cash flows. Several relevant linear programming problems are depicted as well. Particularly, the author focus on Present Value (PV) of a series of cash flows with flat and variable annual discount rate, Present Value of an ordinary and deferred annuity (i.e. finite number of equal and unequal cash flows correspondingly), perpetuity (i.e. infinite number of equal cash flows). In general, Capital Budgeting theory is known for deterministic capital budgeting and capital rationing LP optimization problems (for example, Weingartner (1963), Kachani and Langella (2005)). Both models compute and select a single or a set of investment projects with a maximal return on investment from the potential candidates. The length of investment lifespan and fixed capital budget constraint are taken into consideration. While capital budgeting model includes borrowing and lending constraints, the capital rationing model does not. Stochastic behavior of these problems is discussed in Kira and Kusy (1988), Kira et al. (2000). The author extended Weingartner's model by adding stochastic constraints and penalties for infeasibility.

The study conducted in 2004 by Lam et al. (2007) unveiled the investigation results about capital budgeting practices used in the real sector. The most popular practices of evaluation investment projects when the cash flows are known became payback period, internal rate of return and net present value.

3.3.1 Deterministic discounted cash flow analysis

The metrics described in this subsection use given or known in advance deterministic values of expected cash flows. They are Payback Period, Net Present Value, Internal Rate of Return, et cetera. Still, these metrics are very popular due to simplicity and straightforward approach. Often, these criteria are not used separately in comprehensive analysis of investments. Instead, it is a quick approach for management to get the signal from investment opportunity if it worth further investigation.

Capital flow indicator

The engaged capital indicator considers updated total capital costs K_t^{tot} at the period t. It includes total investments costs and upgrades I_t^{tot}, and working capital costs for operation W_t^{tot}:

$$K_t^{tot} = I_t^{tot} + W_t^{tot} = \sum_{t}^{T=d+D} \frac{I_t + W_t}{(1+r)^t} \tag{6}$$

where: I_t - annual capital outlays; W_t - working capital injections; r - discount rate. The T-horizon T consists of construction period d and operation period D.

The discounted payback period

This measures the time taken for the cash flow (either discounted or nominal) from an investment to repay the original cost. Discounted Payback period is a very imperfect measure, since it does not consider cash outflows and inflows arising after the payback moment. It will only be meaningful if this indicator is used in addition to Discounted Net Present Value. For the Greenfield plant, the payback period begins at the beginning of operation period D. It ends when the cumulative discounted sum of operation cash flows equals the discounted sum of occurred investments:

$$\sum_{t=1}^{d} \frac{I_t}{(1+r)^t} = \sum_{t=d+1}^{d+T} \frac{P_t}{(1+r)^t} \tag{7}$$

where: I_t - annual capital outlays; P_t - annual profit; r - discount rate; T - term of payback of investments, which consists of construction period d and operation period D. If not discounted, this indicator misleads by computing shorter term of payback on investments than it is in practice.

Net present value model

Net present value (NPV) refers to the discounted sum of the expected net cash flows that consists of cash outflows as capital outlays and cash inflows such as revenues from sales. In other words, NPV is calculated by subtracting the present value of the capital outlays from the present value of the cash inflows. The general formula for computing the NPV as stated in Dayanada et al. (2002) is:

$$NPV = \sum_{t=1}^{T} \frac{C_t}{(1+r)^t} - \sum_{t=0}^{T} \frac{CO_t}{(1+r)^t} \tag{8}$$

where: C_t - cash flow at the end of year t; CO_t - capital outlay at the beginning of year t; r - discount rate at the beginning of year t. The positive NPV value is a signal to invest in a project. The negative NPV absolute value bespeaks project's potential losses, while zero value of NPV sends signals about reimbursement of costs. A major criticism about NPV analysis of real investment(s) is that it favors short-term or low-risk projects.

If an investment appraisal compares industrial plants with different economic lifespan, a Net Present Value comparison is likely to be misleading because it will not be comparing like with like. Dayanada et al. (2002) suggested using Net Present Value of an infinite series of identical projects when considering mutual exclusive projects with unequal lives. Another approach is to use Equivalent Annual Cost (EAC) method to normalize the data. In this thesis, an assumption is made that all plants within GasMat will cooperate and have same finite economic lifespan. Considering high level of complexity and technological interconnections between the plants it does make sense.

The internal rate of return

This indicator has been already mentioned in Martin et al. (1996) in the Subsection 3.1 when economic benefits of industrial park were discussed. The Internal rate of Return (IRR) is the discount rate at which Net Present Value of an investment is zero.

The profitability index

The profitability index (PI) is used in addition to NPV indicator. The investment is profitable if the profitability index (PI) greater than 1, and loss if PI less than 1. If the value of PI index equals exactly 1, the investment produces only a recovering of expenses. The concept is very similar to NPV, but expressed as decimal number:

$$PI = \sum_{t=d+1}^{d+D} \frac{CF_t}{(1+r)^t} / \sum_{t=1}^{d} \frac{CO_t}{(1+r)^t} \tag{9}$$

where: CF_t - cash flow at the end of year t; CO_t - capital outlay at the beginning of year t; r - discount rate at the beginning of year t.

3.3.2 Probabilistic discounted cash flow analysis

Capital budgeting techniques such as NPV, IRR, and Payback Period have been often criticized in the literature for its deterministic behavior when evaluating independent investments. Often, the uncertainty in the analysis is reduced by probabilistic Monte Carlo simulation, sensitivity analysis, risk-adjusted discount rates (RADR) and certainty equivalent (CE) method (e.g. Dayanada et al. (2002)). It is also popular to use probabilistic decision trees (e.g. Neely (1998)), scenario analysis, and fuzzy sets (e.g. Bas and Kahraman (2009), Collan (2004)). Another modern trend to deal with uncertainty in industrial investment is to use Real Option theory (e.g. Neely (1998), Collan (2004), Pindyck (2005) and etc.). However, there is an underestimated evidence of using pure probabilistic DCF techniques. For the first time, a compressive survey about PDCFA was carried out by Carmichael and Balatbat (2008) gathering together 70 references since year 1963 up to day. With an assumption that probabilistic data is available for the parameters, the author focus on probabilistic distribution of present value (PV), future value (FW), internal rate of return (IRR), payback period, and benefit-cost ratio. Both discrete and continuous time period discounting is adopted. Three main parameters of each method are used: discount rate, cash flows, and investment life span. Minimum one, maximum two parameters at a time are treated to be probabilistic in order to avoid intractability of the results.

Probabilistic present value and payback period

In this thesis, implementation of probabilistic cash flow and probabilistic payback period will become a logical extension of currently developed deterministic DCF analysis tool with certainty equivalent (CE) add-in for GasMat Park project. Let's consider the case of probabilistic cash flows with normal distribution for present value. According to Carmichael and Balatbat (2008), the present value for a n-period single investment PV_n, its expected value $E\left[PV_n\right]$, and variance $Var\left[PV_n\right]$ become correspondingly:

$$PV_n = \sum_{i=0}^{n} \left[\frac{X_i}{(1+r)^i} \right] \tag{10}$$

$$E\left[PV_n\right] = \sum_{i=0}^{n} \frac{E\left[X_i\right]}{(1+r)^i} \tag{11}$$

$$Var\left[PV_n\right] = \sum_{i=0}^{n} \frac{Var\left[X_i\right]}{(1+r)^{2i}} + 2\sum_{i=0}^{n-1}\sum_{j=i+1}^{n} \frac{\rho_{ij}\sqrt{Var\left[X_i\right]}\sqrt{Var\left[X_j\right]}}{(1+r)^{i+j}} \tag{12}$$

where: X_i is the net cash flow for periods $i = 0, 1, 2, ..., n$; r - discount rate; ρ_{ij} - correlation coefficient between X_i and X_j. The author also provides references on obtaining estimates for correlation coefficients between cash flows. Other two-parameter cases such as probabilistic cash flows and life span, probabilistic cash flows and discount rate are discussed.

Deterministic nominal payback period concept is regarded as misleading in the literature due to the fact that discounted stream of cash flows is not used. The probabilistic discounted version of payback period was suggested by Weingartner (1969). With cash flows assumed to be normally distributed, constant expectation and constant variance, and the probability distribution of coefficient can be calculated as follows:

$$f(PBP) = \frac{X_0}{PBP}\frac{1}{\sqrt{2\pi kPBP}}\exp\left(\frac{-(X_0 - xPBP)^2}{2kPBP}\right) \tag{13}$$

where: X_0 is the initial investment or capital outflow; x - the uniform stream of cash flows with constant variance k.

Net Present Value under uncertainty

There are at least two techniques to incorporate uncertainty factor when Net Present Value concept is used. They are Certainty Equivalent(CE) method and Risk-adjusted NPV method. Main elements and differences of the methods are shown in the Table 2. In this thesis, the usage of CE method is preferable due to its simplicity and straightforward logic for the end-user. Both methods account for time and risk factor. CE method adjusts expected risky cash flows by introducing decimal subjective coefficient $b_t, b_t \in [0, 1], \forall t \in T$ as a degree of uncertainty of forecasted cash flows. The greater the value of coefficient, the lower the value of uncertainty is accepted by experienced management. The b_t value declines with the growth of t, $t \in T$.

The timing and risk uncertainty factors of the future cash flows from investment are generally captured by accurate estimation of a discount rate r. There is an inverse dependence between the discount rate and timing. The longer in time an investment is, the lower the value of the discount rate on these expected cash flows today. The NPV is very sensitive to the choice of discount rate. A higher uncertainty in expected cash flows is often captured with higher r, which in its turn declines the net present value of future cash flows.

The RADR method adjusts the composite discount rate $k = r + a$, which consists of a risk-free rate r and additional risk premium a. Both NPV_{ce} and NPV_{radr} account for the time value of money by implying a discount factor $1/(1 + discountrate)^t$ increasing exponentially over the time. If a conventional NPV and NPV_{ce} is discounted with a risk-free rate r in order to evaluate the time value of money only, RADR rate $k = r + a$ also involves the estimate of additional risk factor a. The estimation of a factor requires additional computation and knowledge of quantitative CAPM and WACC models. In the capital asset pricing model (CAPM), the expected return (i.e. the discount rate) on a single investment is estimated by comparing it with a portfolio of investments that has a known rate of return.

Overall, the NPV_{radr} has more complex structure than NPV_{ce} and may lead to intractability if used improperly. On the other hand, NPV_{ce} incorporates subjective judgments without a unified and acknowledged quantitative procedure for estimation b_t weights.

Table 2: Risk-adjusted NPV methods

Risk-adjusted NPV methods	
↓	↓
Certainty Equivalent (CE)	**Risk-adjusted discount rate** (RADR)
↓	↓
Risky cash flows CF_t: inflows C_t, outflows CO_t $CF_t = C_t - CO_t, \forall t \in T$	
↓	↓
CF_t converted to their certainty equivalents $b_t, b \in [0,1]\, \forall t \in T$	CF_t
↓	↓
Discount rate r	
↓	↓
risk-free flat rate $r, \forall t \in T$	RADR $k, \forall t \in T$
	↓
k computed by CAPM, Capital Asset Pricing model	k computed by WACC, Weighted Average Cost of Capital model
$NPV_{ce} = \sum_{t=1}^{T} \frac{b_t C_t}{(1+r)^t} - \sum_{t=0}^{T} \frac{b_t CO_t}{(1+r)^t}$	$NPV_{radr} = \sum_{t=1}^{T} \frac{C_t}{(1+k)^t} - \sum_{t=0}^{T} \frac{CO_t}{(1+k)^t}$

3.3.3 Fuzzy capital budgeting techniques

An overview of investment valuation methodology would not be complete if techniques based on fuzzy set theory are omitted. Buckley (1987) considered to use fuzzy cash flows, time period and interest rate in calculation of fuzzy future value (FFV) and fuzzy present value (FPV). Kuchta (2000) used same fuzzy parameters in order to calculate discounted payback period, net present value (NPV) and net future value. Chiu and Park (1994) used fuzzy triangular numbers in his study of fuzzy cash flow analysis using present value (PV) criteria. Kahraman et al. (2002) studied discounted payback period indicator, internal rate of return, and benefit-cost ratio method with fuzzy variables. Finally, about 30 references regarding fuzzy capital budgeting techniques and complete fuzzy linear programming models are mentioned in Bas and Kahraman (2009).

3.3.4 Real Options Valuation models

Despite the fact that some real options models may not hold necessary assumptions for real projects (e.g. Collan (2004)), the ROV models are often considered to be superior to conventional NPV models (Neely (1998), Collan (2004), Schwartz and Trigeorgis (2001)). The major argument is that NPV considers a potential investment to be irreversible from the starting period over its economic life ignoring the potential revising options/decisions in the future, and thus underestimating the investment's Net Present Value. On the other hand, real options techniques are often modeled for traded risky assets. The call option techniques are founded on two most known models: the Black-Scholes pricing formula for continuous evaluation of the asset (i.e. there are no price jumps) and the Binominal Option pricing model with discrete time framework. The real investments (e.g. building and running a DRI plant) are often not traded assets as opposed to issued share capital of the owner of DRI plant. Moreover, these investments are not even venture capital investments (i.e. risky financial investments with significant growth opportunities) that are often analyzed by ROV models. In support of discounted cash flow techniques, Myers (1984) argues that NPV model is perfectly adequate for valuing projects with safe cash flows, just as it is for valuing bonds.

Nevertheless, the ROV techniques became powerful tools of valuation real investment projects due to consideration opportunity costs of waiting under uncertainty. A comprehensive survey of real option valuation methods is presented in Neely (1998), Trigeorgis (1995) and Collan (2004), while classical readings collected and edited by Schwartz and Trigeorgis (2001) became a handbook in Real Options and Investment analysis. It contains 39 fundamental studies. Guimaraes (2009) has collected around 200 references on the real options, including recent sources. All real options studies consider either existing real options theory or applications. The studies include growth options, staged investments, contracts, expansions, valuing single and multiple options in static and dynamic environments. The discussion of operation below-equilibrium rate of return is provided in McDonald and Siegel (1984b). The option to shut down a money-losing operation, and the following future option to re-open under favorable market conditions is considered in McDonald and Siegel (1984a). An option to abandon (i.e. permanent shutdown) a project is discussed in Sachdeva and Vandeberg (1993), where the author performs an analysis of building a Greenfield manufacturing plant and examine a pessimistic option of halting production under unfavorable market conditions. Sanchez (1995) uses options pricing models to describe how it influences product development strategy and production planning. Many of ROV models are based on case studies with a strong focus on natural resource driven investments. Brennan and Schwarz (1985) discusses an option to wait regarding favorable market conditions and long-term supply contracts in the copper mining industry. The works by Siegel et al. (1987) and Kemna (1993) study favorable timing to invest as well as growth and abandonment options in oil and gas industry. Very few authors discussed usage of Real Option pricing models regarding valuation of industrial investment project in the steel processing industry (e.g. Collan (2004)).

In this thesis each of the GasMat plants is subject to a composite three-step investment analysis which involves advanced forecasting of time-series, production simulation, and usage of NPV and ROV methods under uncertainty. Despite the uncertainty in the long-term planning, taken steps along with favorable long-term market conditions increase the efficiency of the suggested composite investment approach. Besides, the historical market trend gives the evidence of consistent growth in global DRI and crude steel production, consumption and pricing. The steel price time-series and other statistics are shown in Figure 13. There is also a potential in Norwegian crude steel and by-products import substitution.

The Black-Scholes model adopted for real projects

The Black-Scholes Options Pricing model was suggested by Black and Scholes (1973) as a financial analytical tool for European Call Option. The Option is the right, but not the obligation to buy a stock, bond, commodity, or other instrument at a specified price (i.e. stock price) within a specific time period (i.e. option term). The owner usually executes a Call Option (i.e. buys stock, bond, commodity, etc. at initially agreed stock price) if the exercise price (i.e. selling price of stock, bond, etc. during the option term) is higher than initial stock price, thus yielding a profit. Merton (1973) generalized the formula for analysis of American Call Option. The distinction between European and American Call Option lies in the tractability of the option term, particularly when to execute an option. If an American Call Option permits its execution during the option term, the European Call Option does not.

The tool became a breakthrough in Option theory and initiated a great number of studies reported above. Most of the Real Options models are based on original studies of Black-

Scholes model. Recently, Zmescal (2001) suggested a methodology by comprising the Black-Schole Real Option model with fuzzy sets theory. Collan (2004) took a step further and suggested a fuzzy(hybrid) real investment valuation (FRIV) model for large industrial investments. It combines the conventional Black-Scholes pricing formula, utilizes fuzzy sets and discounted cash inflows and outflows. Collan (2004) admits the scarcity of applications tested. By reason of that and lack of similar studies this approach is omitted in this thesis. Instead, the classical pricing option on a dividend-paying stock with timing (Merton (1973)) is depicted below. It was adopted for real options just by interpretation of the variables. The current value ($W(S_0, \tau)$) of real option on cash flows is computed as follows:

$$V = S_0 \exp^{-\delta\tau} N(d_1) - X \exp^{-r\tau} N(d_2) \tag{14}$$

$$d_1 = \frac{\ln(S_0/X) + (r - \delta + \sigma^2/2)\tau}{\sigma\sqrt{\tau}} \tag{15}$$

$$d_2 = d_1 - \sigma\sqrt{\tau} \tag{16}$$

where: $\tau = T - t$ is the time to maturity of the option from the point of current period t, the time to termination of the project (i.e. GasMat plant); σ represents the volatility of the logarithmic rate of return of S_0 (i.e. standard deviation of the annualized continuously compounded rate of return on the stock); r is a risk-free interest rate (annualized continuously compounded money market rate on a safe asset with the same maturity as the expiration term of the option); δ - payout rate on the plant. Payout represents the opportunity cost of delaying completion of the plant, or the expected net cash flow accruing from a producing plant. It is measured on an overall or periodic basis as either a percentage of the investment's cost, or real money term amount. A periodic payout rate can be derived as a percentage when net cash flow is divided to capital outflow. The normal distribution function $N(d)$ represents the probability that a random draw from a standard normal distribution will be less than d; ln() - natural logarithm function. Specifics of treatment of some variables is discussed in Table 3.

Table 3: Treatment of some Black-Scholes variables in financial and real option model

Financial call option interpretation	Variable	Real call option interpretation
Time to maturity of the option	$\tau = T - t$	Time to termination of a plant
Stock price	S_0	Present value of expected cash flows from a plant
Exercise price	X	Present value of capital outflows, fixed costs

There are also some specifics in the treatment of the model's assumptions regarding real option. All assumptions may not be equally hold in a particular case as in original Black-Scholes model. See Table 4 for details.

Table 4: Treatment of some Black-Scholes assumptions with respect to ROV

Financial call option	Variable	Real call option
The analyzed stock is traded		The underlying asset (i.e. plant) is not traded
The markets are complete, efficient (i.e. w/o speculation)		The markets are often monopolistic or oligopolistic due to uniqueness and high entry costs of Investment
Constant risk-free interest	r	Industrial investment have long lifespan ($>$10-20 years) and risk-free rate changes in long-term (i.e. U.S. Bond rates: LT Composite ($>$10yrs), Treasury 20-yr CMT)
The variance is known, deterministic and constant over the option term (i.e. past time-series are used)	σ^2	The variance is less known and does not remain constant in the long run(i.e. expected future time-series are forecasted)
Option exercise is instantaneous		Exercise is postponed in time (i.e. building a plant)

Overall, both the NPV and the real option models can be used in the investment appraisal. The latter may serve as a supplementary capital budgeting tool, and a step four of the investment approach suggested in the thesis. Trigeorgis (1995) argues that conventional static NPV should be seen as necessary input to an option based models forming an extended NPV analysis.

3.4 Quantitative time series analysis

Valuation of large industrial investment with a riskless/moderate rate of return requires precise ex-ante forecasts of cash inflows and outflows from the Plant. These flows directly depends on various exogenous factors over the time such as market requirements and prices for the output products, costs of input materials, etc.. This subsection discuss several methods of analysis past and future time series.

3.4.1 Standard and advanced methods

Some quantitative techniques use time series to build time-trend projections of a particular variable (e.g. price of crude steel in $/ton, annual import quantity of crude steel in tons, power price in \$/kWh) over a planning horizon. These methods are correct if there is an evidence of a consistent increase or decrease and/or repeating pattern over the time. Thus, a simple component analysis is performed. Linear filters (e.g. moving averages) allows to decompose the time series into a linear/non-linear trend T, cyclical variation C, seasonal component S and a remainder as random variation R. Usually it exhibits additive $Y = T + C + S + R$ or multiplicative $Y = T * C * S + R$ relationships.

Other methods are based on regression analysis, which estimates relationships between dependent and independent (explanatory) time series variables. Then a regression model is build using statistic tests (e.g. statistical hypothesis T-test), and future time period value can be predicted.

Briefly, quantitative cash flow forecasting techniques can be split into standard an advanced methods. Standard techniques are based on ordinary least squares (LS) regression analysis and include: two-variable regression model, trend lines (e.g. linear and non-linear such as quadratic, exponential, logarithmic), moving averages (e.g. simple moving average, weighted moving average, exponential smoothing). The advanced methods comprise (generalized) autoregressive conditional heteroscedasticity (G)ARCH model, autoregressive integrated moving average (ARIMA) model, etc. These techniques remove trend by differencing time-series in order to determine hidden lag pattern by calculation of autocorrelation coefficients (ACF).

Forecasting cash flows and inputs of a hypothetic plant often implies long-term economic lifespan and, thus impose limitations on applied methods. There is a need for large set of observations regarding improving accuracy and identifying more data patterns. Short-term forecasts fluctuate less than long-term predictions.

3.4.2 Sources of data

The GasMat Park project aggregates several production facilities that are depicted in detail in Appendix B. However, the developed DDCFA investment analysis tool is only applied to one of the major production units (e.g. Steel Plant) for demonstration purpose. The investment appraisal approach suggested in this thesis consists of a three step valuation process: forecasting of price and quantity series of inputs and outputs, running production planning model (i.e. simulation of product quantities to be produced over a plant lifespan and expected cash flows), DDCFA and investment analysis. Since Norway is not a DRI or major crude steel producer, there are very few Norwegian industry sources (e.g. web servers of *Statistisk sentralbyrå, Norsk Stål and Norsk Stålforbund*) that posses partial relevant data. Most available free international sources are also Internet based. Relevant series data is available at web servers of London Metal Exchange (LME), World Steel Association. The latter was previously known as The International Iron and Steel Institute (IISI). The historical price series for power can be obtained at the web server of Norwegian Power and Gas Exchange.

These data includes Norwegian import and export series of crude steel in value and quantity terms; global series of price-indices and quantities for inputs (e.g. DRI, steel scrap, kWh) and outputs (e.g. crude steel, steel products). In addition, the following data is compulsory for investment analysis: expected capital and operation costs of a plant over its economic life; tax rates, borrowing and discount rates, inflation rate or GDP deflator. It was considered to use long-term risk-free interest rate series from a conventional source such as U.S. Department of the Treasury, while the latest statistics regarding operating margin and average discount rate in the steel industry is presented by World Steel Association.

4 The DDCFA model structure

4.1 Definition of cash flow integral components

The capital budgeting theory defines a *cash flow* as the amount of currency units received and paid by the firm at particular points in time. A concept of cash flows, in more detail a concept of *aggregated cash flow* is widely used in this thesis. It should not be confused with accounting profit or income terms. The aggregated cash flow sums up every inflow and outflow that occurs during a period $t, t \in T$(e.g. year) at one single point (e.g. end of fiscal year). For the purpose of simplicity, expected aggregated cash flows will be simply mentioned as cash flows (CF). There are two types of CF that are often described in the literature: Capital cash flows and Operating cash flows. The Capital cash flow includes:

- *an initial investment or initial capital outlay*, which falls one-time at the end of the base date $t = 0$ of a project. It includes facilities costs and initial working capital for GasMat Plant(s) production activities. The costs of establishing the facilities contain preparation costs for land site, buildings, process machinery, engineering and construction costs, etc..
- *additional investments* often include office equipment, overhead costs, and working capital upgrades for any period $t, t \in T$, where T is an economic life span of Plant
- *terminal cash flows.* These one-time flows happen at the very end of economic life span. It considers the recovery of remaining working capital (i.e. a cash inflow) from operations, cost of demolishing the facility (i.e. cash outflow), and/or *salvage value.* The latter is a cash inflow from selling assets "as is"

In GasMat project, the majority of capital outflows are meant for Greenfield GasMat Plants (i.e. new). Exceptions are Natural Gas Processing Plant and Methanol Plant that have been already brought into operation at StatoilHydro site in Tjeldbergodden, south-west of Trondheim.

Operating cash flows occur during the operations phase of GasMat only. The operation stream starts after upon completion of the construction phase and commissioning the plant. Operation cash flows include:

- a gross income from sales, depreciation and allowances (cash inflows)
- purchasing of raw materials, taxes, interest, payments for wages (cash outflows)
- other direct variable costs

Dayanada et al. (2002) give evidence of typical integrated elements of cash flow and explain them in detail. There are several other integral components to focus on when developing the DDCFA model. The correct treatment of taxes, inflation rate and discount rate affect the net present value of investment. Investment costs and upgrades, sunk costs, depreciation, working capital, overhead costs, labor costs are subject to discussion too. Without these elements a cash flow analysis would have been very inaccurate and incomplete.

Investment upgrades

Modifications, increase in productive capacities, purchasing of new equipment might increase the economic life span of a Plant. These are typical items that are treated as investment upgrades. The model's notation defines them as capital cash flows in the DDCFA tool.

Sunk costs

Sunk costs always occur in the past and are irreversible. It is money that have been spent before the investment is carried out. Sunk costs physically do not have option to be recovered in order to be counted as an opportunity cost. In this thesis, an example of sunk costs will be the total costs of SINTEF R&D about GasMat project. The funds spent by the vendors, including potential GasMat Park members will not be available any time in the future. Thus, there is no opportunity to put that money on deposit in a bank with a risk-free investment rate as opposed to a risky and uncertain alternative of investing in GasMat Park.

Overhead and labor costs

In this thesis, an investment analysis omits overhead and labor costs for the simplicity of the analysis. It is due to its low contribution to overall capital outflow and purchasing of raw material for GasMat Plant(s). Another reason is a lack of explicit estimates of such costs. In general, overhead costs are periodical expenditures that can be measured as percentage of investment costs in facilities. The repairs, insurance, property taxes are examples of overhead costs.

Working capital

The working capital is a part of capital outflow for every Plant in the GasMat Park. It represents a capital of a firm that is currently tied up in operating assets (i.e. cash, inventories of raw materials, inventories of finished goods, unpaid customer's bills) plus liabilities (i.e. unpaid firm's bills to suppliers). In other words, these are investments that are required to establish physical and monetary resources connected with production during the operating horizon. In general, a correct estimation of working capital and optimization of firm's assets and liabilities lead to increase in sales of finished goods, while lack of working capital may cause the disruption in firm's supply chain and day-to-day operations. As a rule, the amount of working capital necessary for operation activities is estimated as the percent of initial capital outflow (e.g. 10% of Initial Investment).

Terminal value of investment

When a planned economic life of GasMat Steel Park ends, there will be one more cash flow from every Plant on top of the last period operating cash flow. It is called Terminal cash flow. It collects the salvage value of all ISP assets less property tax and full recovery of working capital (i.e. tax-free capital cash inflow) tied up in the cluster during the economic life of Integrated Steel Park.

Discounting and risk-free interest rate

In GasMat investment appraisal, the estimated costs and benefits are spread over a number of years for each plant. Every plant in the Park has probably different cost/benefit ratio and yearly cash flows. In order to measure and compare each plant performance, cost/benefit flows must be normalized. It is done through discounting the stream of costs/benefit yearly flows to get Discounted Cash Flow (DCF). The cumulative stream of discounted costs and benefit flows is called Net Present Value (NPV). Discounting factor $1/(1+r)^t$ has a time preference, measured by riskless interest rate r. Interest rate converts future cash flows to a present value. It is higher in the short run and lower in the long term due to reluctance of getting lower benefits with a lower risk in time. Therefore, discounting gives more weight to cost/benefit flows that arise in earlier time periods t than at the end of lifespan T. It is a common practice to consider a nominal Long-Term Composite Rate on U.S. Treasury Bonds (>10 years) as the risk-free discount rate. For an investment with a very long lifespan (>30 years), a declining long-term discount rate rather than a flat annual rate should be applied. The recent discount rate time-series are depicted in Appendix A.

Depreciation

The depreciation is an accounting term, which is used for allocation of capital investments (outlays) over the economic life of Plant(s) in the GasMat Park. Since it is an element of a Free Cash Flow, it is incorporated in the DDCFA model and computed in the DDCFA tool. The depreciation has a direct effect on tax deduction from operation flow, and thus on profitability, albeit depreciation should not be included in an investment appraisal (i.e. computation of NPV, DPP, IRR, etc..). As of day, there are several widespread methods of computing the depreciation on capital investment and assets. Dayanada et al. (2002) define following methods:

- *straight-line method (SLN)*. It is the most used and the simplest way of allocating of the initial investment outlays (in actual numbers) over the economic life of investment. Additional capital investments have to be calculated separately using a new base time period. It is usually the beginning of actual year of committing the additional investment
- *reducing balance method (RB)*. This method allocates a fixed percentage of investment capital's written value every year. It is known as accelerated depreciation method. It leads to lower tax deductions in the beginning of investment projects and higher tax deductions at the end of economic life of investment.
- The method of *sum of the year's digits* allocates a reducing proportion of the asset's cost in each year. It is an accelerated depreciation technique.

In this thesis the SLN method has been incorporated into DDCFA model and tool. An advantage of such decision is that SLN method has been known for its simplicity and provides uniform distribution over the whole economic life span of the facility. SLN method is not an accelerated depreciation type. It can be interpreted as its disadvantage due to understatement of benefits from tax deductions if only the net present value of the project is positive.

Interest or cost of capital charge

It is another element of Free Cash Flow. The cost of capital charge is not included in an investment appraisal, albeit it is present in operation cost statement. The cost of capital charge (interest) reflects the opportunity cost of involved or borrowed funds tied up in capital assets. In this thesis, the author does not take into consideration the way of financing GasMat Project. Neither internal funds nor borrowing funds and interest have been included in the DDCFA model. It is not a focus of the thesis to decide how to raise the funds, but to estimate the return on investment and other indicators.

Taxes

The taxes represent a significant post-production real cost for industrial facility, since the tax rate is a revenue sharing mechanism between the GasMat Plant, local communities and the state. The profitability of investment in GasMat Plant(s) is very sensitive to Norwegian *taxation rules and rates*. The longer an economic life of project is, the higher the uncertainty of expected future tax rate for the GasMat Consortium is. In this thesis, a simple flat rate of corporate tax per year has been taken into consideration by default. The corporate tax can be different regarding different industries. For example, the Norwegian Oil and Gas industry is subject to composite corporate tax, including the base rate of 28% and additional variable tax up to 50%.

The DDCFA test case described in Section 6 assumes that metallurgical industry is subject to flat tax rate of ca. 30% for the simplicity of calculations. It is also assumed that corporate income tax rate can be changed on periodic basis (i.e.yearly). Investment allowances in the form of additional tax benefits are not considered in DDCFA model due to complex tax rules attached. The value added tax (VAT) was excluded from the model as it is a transfer payment. It arises from different contractual arrangements between plants and suppliers, such as in-house supply versus buying in. The VAT exclusion reduces risk of miscalculating recoverable value added tax.

Inflation or price base

When analyzing cash flows a choice has to be made about the treatment of inflation with respect to relevant discount rate. The cash flows can be expressed at constant price levels without an adjustment for inflation. Alternatively, the annual cash flows can be up-rated each year to incorporate expected specific inflation (i.e. GDP deflator). Purchasing time series prices for raw materials and selling prices for steel products are often available in nominal values. In this thesis, nominal cash flows and nominal discount rate is considered.

Although, they can be easily converted into *real* terms if to use Fisher's equation:

$$(1 + i_t) = (1 + r_{t+1})(1 + \pi_{t+1}) \tag{17}$$

$$\Rightarrow i_t = r_{t+1} + \pi_{t+1} + r_{t+1}\pi_{t+1} \tag{18}$$

$$\Rightarrow i_t \approx r_{t+1} + \pi_{t+1} \tag{19}$$

where i is the annual nominal interest rate expressed as a decimal value, r - annual real interest rate expressed as a decimal value, π - annual inflation rate (i.e. value of GDP deflator) and t is a time period.

Definition of the time horizon

The choice of the *time horizon* for an investment appraisal of GasMat Park can have a significant effect on the outcome, and should always be long enough to cover all of the important cost outflows and benefit inflows between plants, suppliers and industrial customers. The appropriate time horizon takes into account the potential of the current DRI, Steel technology over the time, economic life span of facilties. Based on industry evidence, the economic life of DRI and Steel facilities lasts for 15-20 years, for example.

4.2 Assumptions imposed onto DDCFA model

By default the DDCFA model takes care of *yearly* expected cash flows falling at the end of calendar year or several other assumed time intervals. The year-end assumption is concurrent with the fact that Norwegian fiscal year ends 31 December.

Working around long-term uncertainty in DDCFA model

Shortening the investment analysis term from full real economic lifespan (i.e. average lifespan of capital assets in steel industry is between 15 and 20 years) to mid-lifespan (i.e. 7-10 years) reduces the uncertainty regarding production planning and forecasting of cash flows. However, the shorter time intervals might artificially pitch the NPV value too low for the reason that significantly large capital outflows have to be depreciated twice faster now. The depreciation allowances reduce the present value of benefit stream and tax payments over the time, since they are simply excluded from the Net Income Flows in the Cash Flow statement of the Plant. The types of GasMat capital assets (i.e. buildings, equipment), minimal depreciation term and allowed methods of depreciation (i.e. SLN, RB) are subject to Norwegian tax legislation.

With respect to mutual limitations, the major advantage of Real Option Valuation metrics over pure Discounted CFA criteria (i.e. NPV, DPP, etc.) is that Real Options models are better in long-term estimation of the investment value under uncertainty. If only the discounted cash flow metrics are considered in the analysis, there is still a way to work riks around. For example, the suggested in this thesis a three-step investment approach can be applied. It is based on time-series data valuation, usage GasMat production model and DDCFA tool. Since the composite approach relies on GasMat production model, the conducted literature research in 3.2.2 points at methods of modeling risky investment in productive capacities over the time.

Alternatively, the Black-Scholes real option model can be used as a supplementary metric to evaluate Net Present Value of investment under uncertainty over time. When the investment opportunity is worth more than capital outflow connected with investment (i.e. NPV >0), the decision to wait or proceed with investment opportunity is justified. If the volatility of rate of return on investment is high enough and the pay-out rate is low enough to secure it, the decision to wait is recommended to accept. The volatility may also rock the profit even if the project produces additional fixed costs while waiting and holding a temporarily deficiently (but risky) investment.

4.3 Formulation of Generic DDCFA model

The followng model illustrates an integral approach for Cash Flow Analysis of all Plants in GasMat Park. The designed investment valuation framework is based on usage of a generic DDCFA model that communicates with already programmed GasMat Network Flow Model (NFM) for operations. Table 5 and Table 6 show the notation used in the model that sheds light on adherent points of both models. These points are Cash Flow variables from Plants $i, \forall i \in P$ such as Total Revenues (TR_{it}), Input Variable Costs (IVC_{ict}), Operation Variable Costs (OVC_{ict}), and Investment Costs (IC_i). In fact, cash flows variables are being imported from GasMat Network Flow model into DDCFA module. These variables are converted into DDCFA input parameters of the investment project if there is no simulation support from operational model.

4.3.1 Notation

Table 5: The notation of Generic DDCFA model

Sets		
C	Set of input/output commodities	
P	Set of Plants plus Market(s)	
Indices		
t	Time period	$t = 1, 2, ..., T$
c	Commodity	$c \in C$
n	Capital upgrade/outflow index	$n \in N$
i, j	Plant(s)	$i, j \in P$
Parameters	**Definitions**	**Units**
T	Length of economic life span	
ρ	Discount factor	(frac)
r^d	Discount rate in period t	(per cent)
$b_{i,t}$	Certainty equivalent coefficient of expected cash flows, $b \in [0, 1]$ at Plant i	(dec frac)
$g_{i,t}$	Growth cost factor implied at the period's $t = 1, .., T$ end, since NFM assumes operational total costs as fixed over time at Plant i	(per cent)
$r_{i,t}^{tax}$	Tax rate in period t	(per cent)
$(svCOo)_{i,T}$	Salvage value of Initial Capital Outflow of Plant i at the very end of T	($)
$(svCO)_{i,T}^n$	Salvage value(s) n of Investment Upgrade(s) of Plant i at the very end of T	($)
$(wc)_{i,0}$	Initial limit of working capital quantity as a rate of Initial Capital Outflow of Plant i expensed in $t = 0$	(per cent)
$(wc)_{it}$	Additional allowance of working capital as a rate of Initial Capital Outflow of Plant i in $t = 1, .., T$	(per cent)
Am_{it}	Ammortization of intangible assets of Plant i in $t = 1, .., T$	($)
Int_{it}	Interest on capital in Plant i at period's $t = 1, .., T$ end	($)
Parameters	**imported from Network Flow Model**	
$(pp)_{ct}$	Purchase price of commodity c in period t	($ per ton)
$(sp)_{ct}$	Sale price of commodity c in period t	($ per ton)
$(link)_{ijc}$	Commodity c is equal 1 if transfer link between Plants i and j exists, 0 otherwise	
$(icl)_{ijc}$	Investment cost of transfer link between Plants i and j	($)
$(cm)_i$	Productive maximal capacity of Plant i	(tons)
$(uic)_i$	Unit investment cost in Plant i	($ per ton)
$(ifc)_i$	Investment fixed cost in Plant i	($)
$(uoc)_i$	Operation unit cost in Plant i	($ per ton)
$(ofc)_i$	Operation fixed cost in Plant i	($)

Table 6: The variables of Generic DDCFA model

DDCFA Variables	**Definitions**	**Units**
Capital CF:		(\$)
CCF_0	Total capital cash outflow, which falls on the end of $t = 0$	(\$)
CO_0	Initial capital outflow, which occurs in the end of $t = 0$	(\$)
$IC_{i,0}$	Initial Investment Costs of Plant i expensed at the end of $t = 0$	(\$)
$ISC_{i,0}$	Installation & Shipping costs of Plant i expensed at the end of $t = 0$	(\$)
$WC_{i,0}$	Working Capital outflow of Plant i expensed at the end of $t = 0$	(\$)
Operation CF:		
CCF_t	Total capital cash outflows that occur in $t = 1, ..., T$	(\$)
$CO_{i,t}$	Investment upgrade/outflow in Plant i expensed in period $t = 1, .., T$	(\$)
$WC_{i,t}$	Working Capital outflow at Plant i expensed at the end of $t = 1, .., T$	(\$)
$OCF_{i,t}$	Operation Cas Flow of Plant i at period's end $t = 1, ..., T$	(\$)
$ONI_{i,t}$	Operation Net Income of Plant i at period's end $t = 1, ..., T$	(\$)
$DE_{i,t}$	Total Depreciation of Plant's i assets at period's end $t = 1, ..., T$	(\$)
$EBT_{i,t}$	Value of Earnings Before Tax in Plant i at period's $t = 1, .., T$ end	(\$)
$TXP_{i,t}$	Value of Tax Payable in Plant i at period's $t = 1, .., T$ end	(\$)
$OTR_{i,t}$	Total Revenue of Plant i gained from operation at the end of $t = 1, .., T$	(\$)
$DeCOo_{i,t}$	Depreciation on CO_0 in Plant i at period's $t = 1, .., T$ end at period's $t = 1, .., T$ end	(\$)
$DeCO_{i,t}$	Depreciation values on $CO_{i,t}$ in Plant i at period's $t = 1, .., T$ end	(\$)
$OTR_{i,t}$	Operation Total Revenue of Plant i at period's $t = 1, .., T$ end from sales to market, not to Plants in GasMat Park	(\$)
$OTC_{i,t}$	Operation Total Costs of Plant i at period's $t = 1, .., T$ end	(\$)
$OFC_{i,t}$	Operation Fixed Non-Investment Costs of Plant i at period's $t = 1, .., T$ end	(\$)
$OVC_{i,t}$	Operation Variable Costs of Plant i at period's $t = 1, .., T$ end	(\$)
$OIVC_{i,t}$	Operation Input Variable costs of Plant i expensed at the end of $t = 1, .., T$ when buying commodities c	(\$)
$OOVC_{i,t}$	Operation Output Variable costs of Plant i expensed at the end of $t = 1, .., T$ when producing commodity c	(\$)
$RWC_{i,T}$	Full Recovery of Working Capital employed in $t = 0, .., T - 1$ in Plant i at the very end of T, or very beginning of $t = T + 1$	
NFM Variables	**imported from Network Flow Model**	
X_{ijct}	Flow of commodities c between Plants i and j in period t	(tons)
Y_i	Binary variable to indicate if a Plant i is in GasMat Park	
DDCFA-NFM	**Adherent Variables: link DDCFA with NFM, otherwise act as**	**input prm**
$IC_{i,0}$	Initial Investment Costs of Plant i expensed at the end of $t = 0$	(\$)
$OTR_{i,t}$	Operation Total Revenue of Plant i gained from sales commodities c to market at the end of $t = 1, .., T$	(\$)
$OIVC_{i,t}$	Operation Input Variable costs of Plant i expensed at the end of $t = 1, .., T$ when buying commodities c	(\$)
$OOVC_{i,t}$	Operation Output Variable costs of Plant i expensed at the end of $t = 1, .., T$ when producing commodity c	(\$)
$OFC_{i,t}$	Operation Fixed Non-Investment Costs of Plant i at period's $t = 1, .., T$ end	(\$)

4.3.2 Integral DDCFA model

The integral DDCFA model includes four adherent DDCFA-NFM variables from WGMO Operational model. Formulation of the integral Gasmat cluster model is split into several sections, including Capital Cash Flows, Operation Cash Flows, Termination Flow, Net Cash Flows and section of performance criteria (i.e. Net Present Value, Black-Scholes-Merton metric).

Net Present Value as objective function:

$$NPV = \sum_{t=1}^{T} \rho_t NCF_t - CCF_0 + \sum_{i=1}^{P} \rho_{t=T} TCF_{i,T} b_{i,t=T} \rightarrow MAX \tag{20}$$

$$\rho_t = \frac{1}{(1+r^d)^t},\ \forall t, t \in T \tag{21}$$

s.t.
Net Cash Flow Module:

$$NCF_t = \sum_{i \in P} b_{i,t} OCF_{i,t} - \sum_{i \in P} b_{i,t} CCF_{i,t},\ t = 1, ..., T \tag{22}$$

Capital Cash Flow Module:

$$CCF_0 = CO_0 + \sum_{i \in P} WC_{i,0},\ t = 0 \tag{23}$$

$$CO_0 = \sum_{i \in P} IC_{i,0} + \sum_{i \in P} \sum_{j \in P} \sum_{c \in C} (icl)_{ijc} (link)_{ijc} + \sum_{i \in P} ISC_{i,0},\ t = 0 \tag{24}$$

$$IC_{i,0} = Y_i (ifc)_i + (cm)_i (uic)_i,\ t = 0; i \in P \tag{25}$$

$$WC_{i,0} = (wc)_{i,0} IC_{i,0},\ t = 0; i \in P \tag{26}$$

$$CCF_{i,t} = CO_{i,t} + WC_{i,t},\ t = 1, ..., T; i \in P \tag{27}$$

$$WC_{i,t} = (wc)_{i,t} IC_{i,0},\ t = 1, ..., T; i \in P \tag{28}$$

Operational Cash Flow Module:

$$OCF_{i,t} = ONI_{i,t} + DE_{i,t} + Am_{i,t},\ t = 1, ..., T; i \in P \tag{29}$$

$$ONI_{i,t} = EBT_{i,t} - TXP_{i,t},\ t = 1, ..., T; i \in P \tag{30}$$

$$TXP_{i,t} = r_{i,t}^{tax} EBT_{i,t},\ t = 1, ..., T; i \in P \tag{31}$$

$$EBT_{i,t} = OTE_{i,t} - DE_{i,t} - Am_{i,t},\ t = 1, ..., T; i \in P \tag{32}$$

$$DE_{i,t} = DeCOo_{i,t} + DeCO_{i,t},\ t = 1, ..., T; i \in P; \tag{33}$$

$$OTE_{i,t} = OTR_{i,t} - OTC_{i,t},\ t = 1, ..., T; i \in P \tag{34}$$

$$OTR_{i,t} = \sum_{c \in C} (sp)_{ct} X_{i,market,c,t},\ t = 1, ..., T; i \in P \tag{35}$$

$$OTC_{i,t} = OFC_{i,t} + OVC_{i,t},\ t = 1, ..., T; i \in P \tag{36}$$

$$OFC_{i,t} = Y_i (ofc)_i g_{i,t},\ t = 1, ..., T; i \in P \tag{37}$$

$$OVC_{i,t} = OIVC_{i,t} + OOVC_{i,t},\ t = 1, ..., T; i \in P \tag{38}$$

$$OIVC_{i,t} = \sum_{c \in C} (pp)_{c,t} X_{market,i,c,t},\ t = 1, ..., T; i \in P \tag{39}$$

$$OOVC_{i,t} = g_{i,t} (uoc)_i (X_{jict} + X_{ijct}),\ t = 1, ..., T; i \in P; j \in P \tag{40}$$

Terminal Cash Flow Module:

$$TCF_{i,T} = (svCOo)_{i,T} + \sum_{n \in N} (svCO)_{i,T}^n + RWC_{i,T},\ t = T; i \in P; n \in N \tag{41}$$

$$RWC_{i,T} = WC_{i,0} + \sum_{t=1}^{T} WC_t,\ t \in 0, T; i \in P; \tag{42}$$

$$(pp)_{ct}, (sp)_{ct}, (icl)_{ijc}, (cm)_i, (uic)_i, (ifc)_i, (uoc)_i, (ofc)_i >= 0\ \forall i, j, c, t; \tag{43}$$

$$(svCOo)_{i,T} >= 0, (svCO)_{i,T}^n >= 0, X_{ijct} >= 0, Y_i \in 0, 1, (link)_{ijc} \in 0, 1\ \forall i, j, c, t \tag{44}$$

4.3.3 Integral DDCFA-BSM model

The suggested in this thesis investment framework also assumes incorporation of Black-Scholes-Merton valuation technique. It means that the integral DDCFA model can be further upgraded to DDCFA-BSM version, which incorporates volatility of rate of return (ROR) over the time into investment valuation. In the Table 7 only new variables and parameters are introduced.

Table 7: The notation of Generic DDCFA-BSM model

BSM Parameters	**Definitions**	**Units**
τ	Time to maturity of the Investment in GasMat Park	
m	Number of current time intervals in the year (i.e. months, qtrs)	
r_d	Discount rate yearly	(per cent)
BSM Variables		
r	Annualized compound interest rate	
σ	Standard deviation, over logarithmic rate of return $\ln(RoR_t)$	
$\ln(RoR_t)$	Logarithmic Rate of Return on the capital in period t	

For the revision of old DDCFA notation, the reader should refer to Table 5 and Table 6. The original Black-Scholes-Merton notation has been discussed in Subsection 3.3.4, Table 3 and 4.

Black-Scholes-Merton Value criterion as objective function:

$$BSMV = S_0 \exp^{-\delta\tau} N(d_1) - X \exp^{-r\tau} N(d_2) \tag{45}$$

$$d_1 = \frac{\ln(S_0/X) + (r - \delta + \sigma^2/2)\tau}{\sigma\sqrt{\tau}} \tag{46}$$

$$d_2 = d_1 - \sigma\sqrt{\tau} \tag{47}$$

s.t.

$$S_0 = \sum_{t\in T}\sum_{i\in P} OCF_{i,t} + \sum_{i\in P} TCF_{i,T},\ t = 1, ..., T; i \in P \tag{48}$$

$$\tau = T - t_0,\ t = 0, ..., T \tag{49}$$

$$\delta = \frac{(NPV/CCF)}{\tau} \tag{50}$$

$$CCF = CCF_0 + \sum_{i\in P}\sum_{t\in T} \rho_t CCF_{i,t},\ t = 1, ..., T; i \in P \tag{51}$$

$$X = CCF \tag{52}$$

$$r = (1 + \frac{r^d}{m})^{m\tau} \tag{53}$$

$$\sigma = \sqrt{\frac{\sum_{t=1}^{T}(\ln(RoR_t) - \ln(\bar{RoR_t}))^2}{T-1}} \tag{54}$$

$$RoR_t = \frac{\sum_{i\in P} OCF_{i,t}}{CCF} \tag{55}$$

Statistical functions used in BSM criterion:
Standard Normal cumulative distribution (i.e. over T-horizon)

$$N(x) = \frac{1}{2}(1 + erf(\frac{x-\mu}{\sigma\sqrt{2}})) \tag{56}$$

Error function

$$erf(x) = \frac{2}{\sqrt{\pi}} \int_0^x \exp^{-t^2} dt \tag{57}$$

5 Implementation of DDCFA tool

MS Excel 2007 spreadsheets have been used for development of a Generic DDCFA Tool. The necessary code and the graphical user interface (GUI) have been coded in Microsoft Visual Basic for Applications Version 6.5. The developed DDCFA prototype was verified for absence of logical errors both in formulas and functional relations. Since the intended level of performance was achieved, the DDCFA tool was considered as practicable to apply for investment valuation of the GasMat Plant(s).

In this thesis, the input parameters for the DDCFA tool are imported from GasMat Mass Balance production model. It was coded in Xpress-IVE environment, which includes program editor, compiler and a solver engine. The model/tool is configured to communicate with MS Excel spreadsheets by means of SQL database computer language. The latter is used for storage of input and output data. Since the DDCFA tool operates with GasMat mass balance model cash flow output, it was decided to develop the investment analysis tool in MS Excel environment. Besides, as opposed to scientific Xpress-IVE environment, MS Excel is well spread in business community in day-to-day operations.

The developed DDCFA tool can be visually split into several areas such as system settings, exogenous economic parameters, cash flow analysis module and set of performance criteria. The Cash Flow statement of a Plant is represented by Capital Flow, Flow of Operations, Terminal and Net Cash Flow. The numerical output results are depicted in charts and scalable tables. There are also auxiliary VBA settings and developed procedures that are responsible for the dynamic nature of the application and graphical user interface.

Overall, the DDCFA tool has two levels of analysis and two template levels. First, it is oriented for investment appraisal of a particular GasMat Plant with different cost/benefit flow design. Second, the performance of GasMat park as a consortium of Plants is being evaluated. Both templates have similar design and use the same analytical metrics, except for cost/benefit flows arising when there is cooperation between Plants within GasMat Park. The similar level of flexibility was initially assumed in GasMat production tool developed by SINTEF.

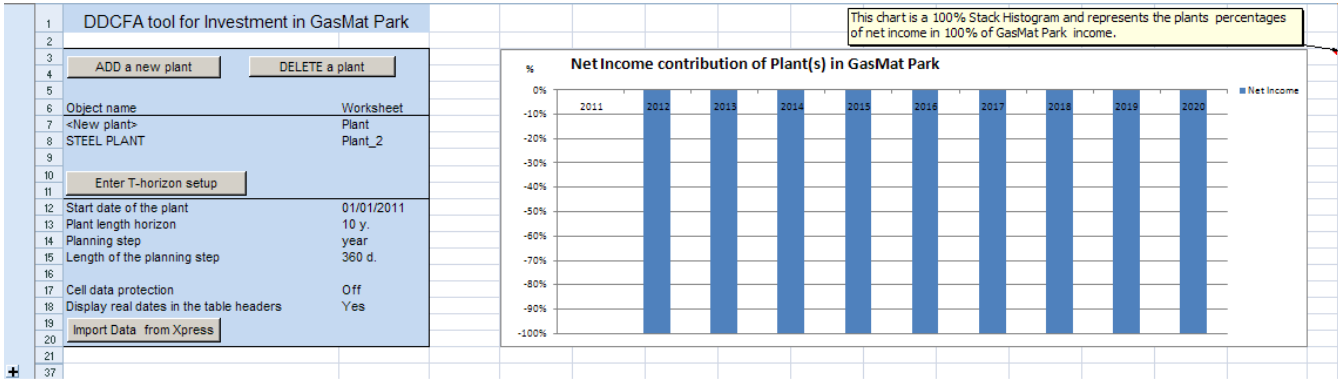
5.1 System settings of DDCFA tool

The system settings are represented by timing settings and dynamic cost/benefit fields that are usually in focus prior to investment analysis (i.e. length of T-horizon, structure of costs, sources of income). Through the setup menus of DDCFA tool the settings and inputs affecting the investment design of the GasMat Plant can be accessed and changed at any point in time. For example, the system menu designed for the overall GasMat Park template is presented in Figure 1, and the system menu of a GasMat Plant template is depicted in Figure 2.

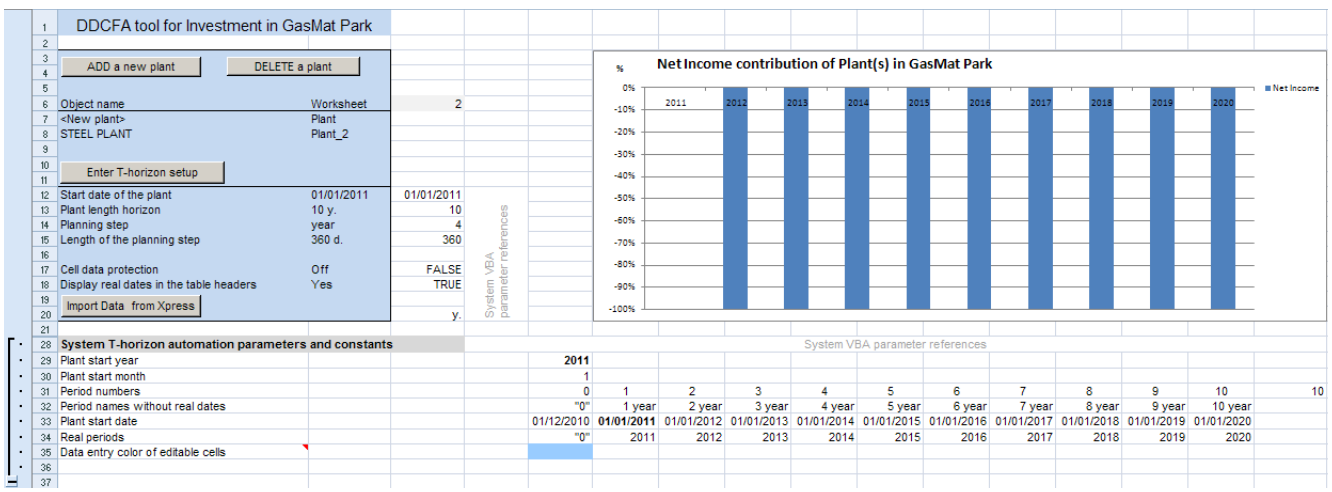
Unified dynamic planning horizon

The time horizon is a dynamic and a core feature of the DDCFA tool. The developed tool allows to change planning horizon with one click and observe the changes with new settings instantly. The Economic Life Span settings are depicted in Figure 2(c) and include multiple time modes for better scaling analysis. There are several periodical settings incorporated into DDCFA tool. The DDCFA tool can represent cash flow stream on monthly, quarterly, 6 months and yearly basis. At every turn of a time mode the model automatically recalculates the parameters, variables and objective functions. Upon the request of the end-user numerical/relevant or real calendar dates can be passed into the system. For the consistency of the results, the DDCFA tool is programmed to synchronize changes in time horizon for all facilities in GasMat Park.

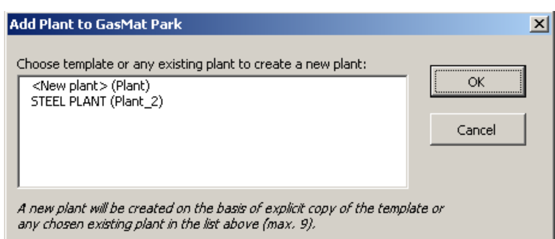
Since the planning T-horizon represents the economic life span of investment, it can be split into construction, commissioning and termination phases. It is illustrated in the Figure 3. For the reason of simplicity it is often assumed that the major capital outflow occurs in $t = 0, t \in T$ (i.e. Year 0) representing an entirely planning and construction phase. Usually, the construction of the Steel Plant takes 3-4 years before the commissioning of the Plant. This situation can be simple simulated during the commissioning phase. The planned construction activities during the specified time periods only generate negative operation cash flows, since there are zero cash inflows and correspondingly allocated negative flows of investment (i.e. outflows).



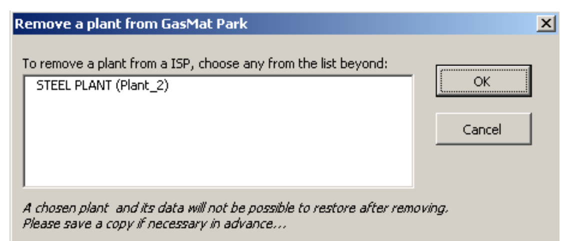
(a) Reduced view of system menu



(b) Full view of system menu

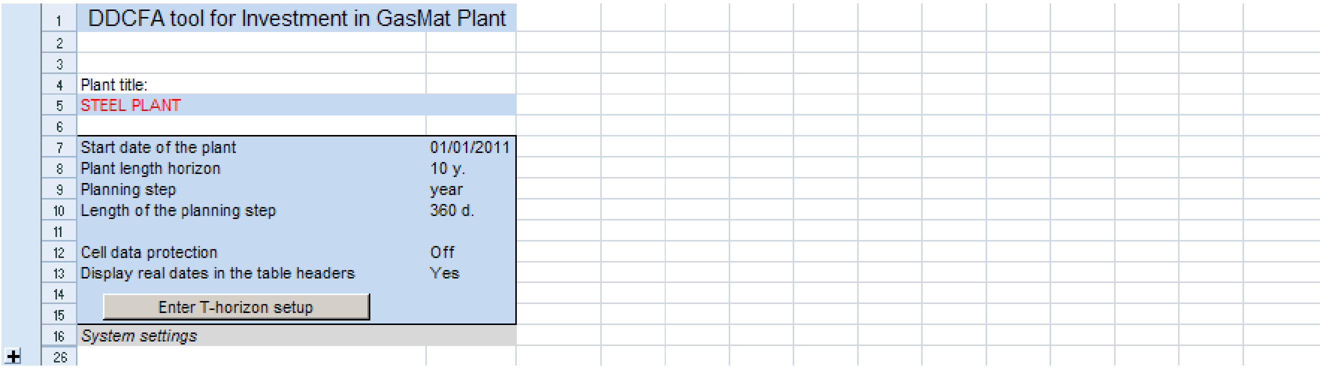


(c) Submenu for Plant Addition

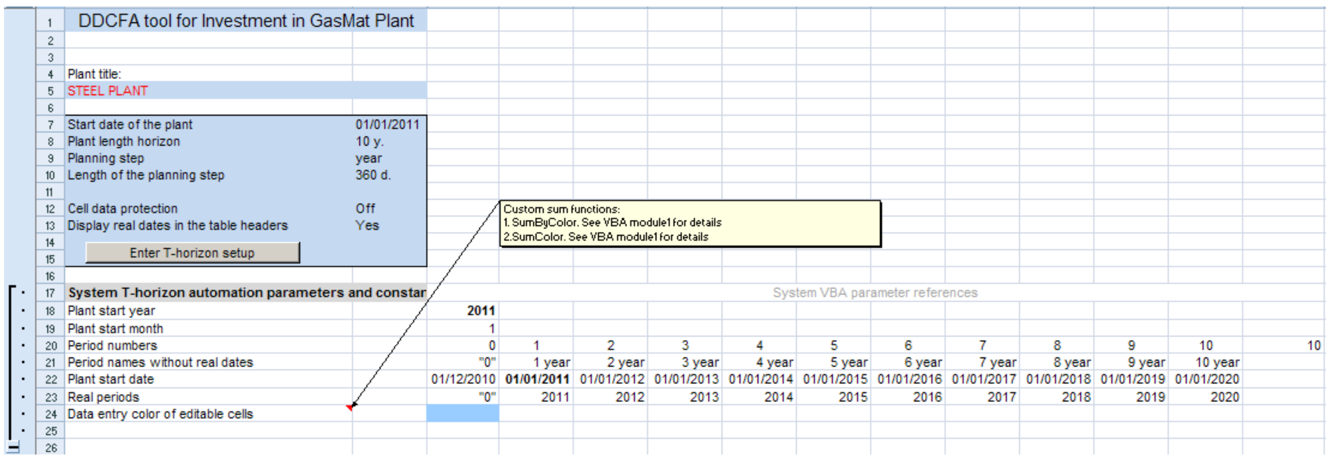


(d) Submenu for Plant Removal

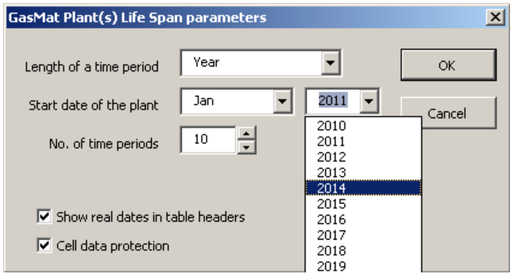
Figure 1: DDCFA design of GasMat Park system menu



(a) Reduced view of Plant menu



(b) Full view of Plant menu



(c) DDCFA T-horizon setup menu

Figure 2: DDCFA design of GasMat Plant menu

By default the operation phase lasts from $t = T - D$ until the end of period $t = T$, where D is a number of periods in construction phase. The Termination period T of DDCFA tool is designed as a separate time phase due to several reasons. The Capital Budgeting theory often assumes termination to occur instantly at the very end of operation phase. In practice, the termination of the Plant takes longer (e.g. up to a year) and includes recovery of working capital, sale of inventories, clearings the accounts, closing down the production site, etc.. Thus, it is wiser and less complicated to calculate termination flow separately and apply the appropriate discount factor for $t = T$ if instant termination is assumed, and $t = T + 1$ if the termination lasts up to a year. When the Net Present value is computed, the discounted Termination Flow is simply added to Net Cash Flow.

Base date

The base date $t = 0, t \in T$ is designated as the end of zero period (i.e. the last day at the end of Year 0). It represents the formal start date of the investment. So, initial capital expenditures are assumed to happen at that date. Capital outflows that fall within the base period Year 0 are not discounted. Capital outflows, operation inflows and outflows are often assumed to be computed at the yearend for the consistency of calculations in the DDCFA model.

The start date and the length of economic life span are calendar based in the DDCFA tool. The expected future cash flows that will take place starting from $t = D + 1, t \in T$ are being estimated with respect to real (i.e. XNPV, XRR) and relevant (i.e. adjusted to a planning step NPV, IRR, etc..) metrics. In this thesis, the start date for the GasMat plants is synchronized and assumed to fall on the same date considering GasMat Park as a Consortium with a single technological supply chain and central planner. As shown in Figure 1(b), the base date, length of planning horizon, and planning step are available in setup menu of Plant(s) and main menu of the GasMat Park.

Full and limited access to the model core

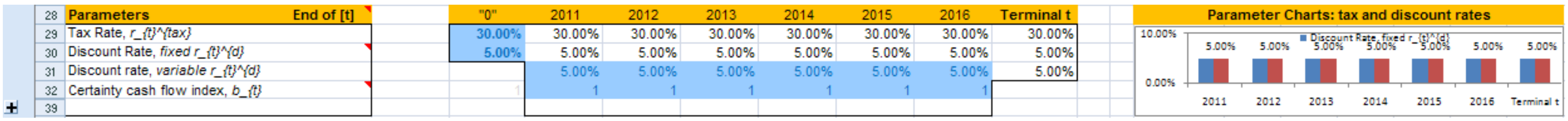
The advantage of the DDCFA tool is that it can be totally reconfigured and customized by the end-user at any time. The model and settings behind the spreadsheets are completely editable. Although, for the purpose of avoiding unwanted changes in the system the data security feature has been implemented. When it is enabled, the user is only allowed to work with parameters and adjustable settings of the model that are highlighted in blue color and/or blue font.

5.2 Exogenous economic parameters module

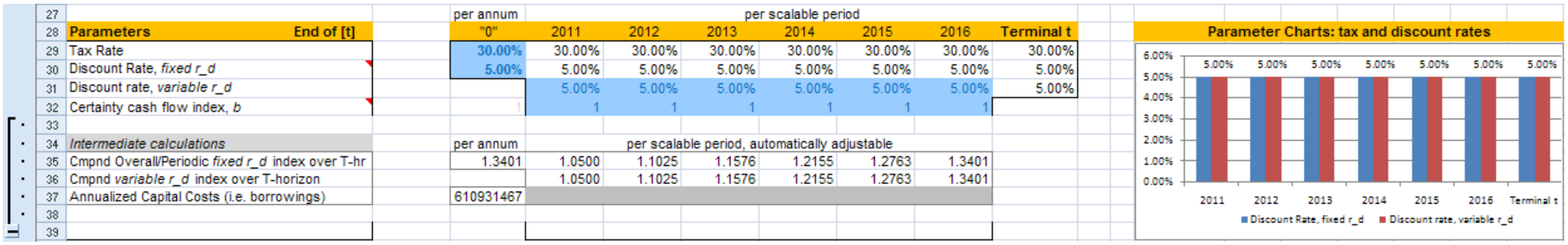
In this subsection of the model the user is responsible for the input of tax rate, certainty cash flow coefficients and discount rates denoted as r_t^{tax}, r_t^{disc} and b_t correspondingly. The discount rate r_t^{disc} is the interest rate that a company is charged to borrow short- and long-term funds from eligible depository institution such as banks. Usually it is compared with a risk-free interest rate (e.g. The LT Rate for USA Treasury Bonds $>$10yr is about 4% per annum. The sources of data for DDCFA tool are discussed in Appendix A. The DDCFA tool treats the fixed and variable discount rate differently, although they are calculated simultaneously:

- *fixed* discount rate represents a single rate per annum that is used over T-horizon. The rate is adjustable with respect to currently used planning step
- *variable* discount rate. This rate should be entered manually in each period. If it hasn't changed since the last period, the same value is to be entered. It is not a self-adjustable rate with respect to planning step and time scale. The user is responsible for the input of correct and logical rate values regarding appropriate period interval (e.g. monthly, quarterly or yearly rate).

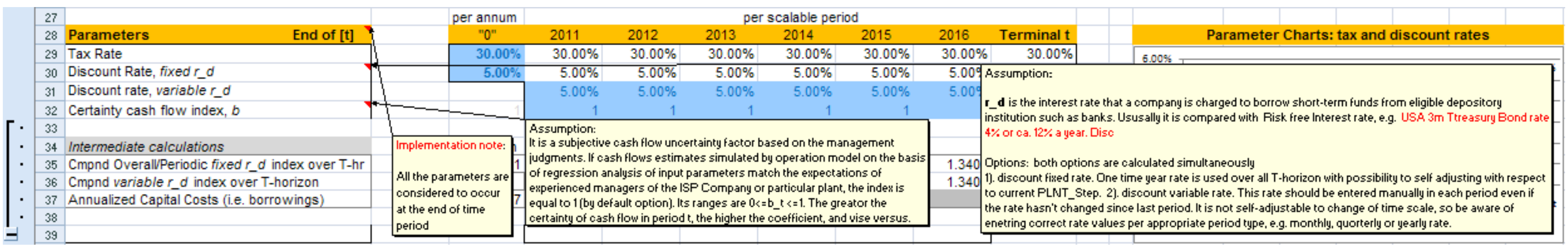
Exogenous parameters of the DDCFA tool are depicted in the Figure 3. Certainty cash flow index $b_t, b \in [0, 1]$ is a subjective index that is based on the experienced judgments of the management. It was introduced in order to reduce uncertainty in cash flow expectations. The greater the certainty of cash flow in period t, the higher the coefficient, and vise versus. If cash flows estimates match the expectations of experienced managers of the GasMat Plant/Park Company, the index is equal to 1. By default b_t values are set to be 1 in the DDCFA tool.



(a) Reduced view of parameter module



(b) Full view of parameter module



(c) Implementation comments on module with exogenous parameters module

Figure 3: DDCFA design of Exogenous economic parameters

5.3 Cash Flows Module

The designed Cash Flow statement did not intend to represent a precise cash flow statement regarding standards of US GAAP, IAS, peculiarities of Norwegian taxation and accounting rules. The main purpose was to design a tool that includes modern analytical indicators and practices of investment analysis. Despite the critics, a non-GAAP metrics such as Earnings before Taxes (EBT), EBIT, and Earnings before Interest, Taxes, Depreciation, and Amortization (EBITDA) were partially used in computations. The incorrect treatment of taxes may seriously distort the investment results and payback time. Since many optimization problems aim to maximize profit from operation, the correct definition and treatment of terms such as Profit, Net Income, Free Cash Flow, their relation with taxation and discounting principles are necessary.

The Cash Flow module of DDCFA program considers Capital Flow, Cash Flow Operations, Terminal and Net Cash Flow. The exact implementation of these flows in the DDCFA tool is discussed below.

5.3.1 Capital Flow

The capital cash flow module is designed for data input of initial investment, multiple entries of investment upgrades and working capital injections into the GasMat Plant. The screenshots of this module are depicted in Figure 4 and Figure 5.

Initial investment

Initial investment outflow is generated by Plant's investment costs that are imported from the Xpress GasMat Mass-Balance tool. In addition, there is an entry field for installation and shipping costs. These values are entered once at the base time period (i.e. Year 0).

Depreciation

The calculation of depreciation values is performed with respect to Straight Line Method (SLN).

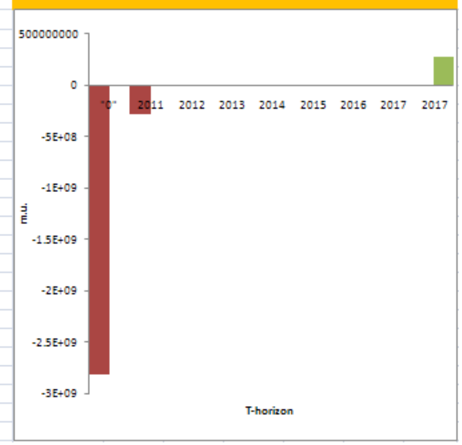
40		+ / - Upgrade									
41	**Cash flow statement**		**Init period**				**operation periods [t;T]**				**End of T**
42	**End of [t]**		"0"	2011	2012	2013	2014	2015	2016	2017	2017
43	**Cash flow: capital**		-2.82E+09	-281900000	0	0	0	0	0	0	281900000
44	Initial investment		-2.82E+09								
45	investment costs in *a plant* assets		-2.82E+09								
46	installation and shipping costs		0								
56	Upgrade_No_		0	-0.01	0	0	0	0	0	0	
65	Working capital (initial and for operations)		0	-281900000	0	0	0	0	0	0	

CFA Charts: economic performance

(a) Reduced view of Capital Flow

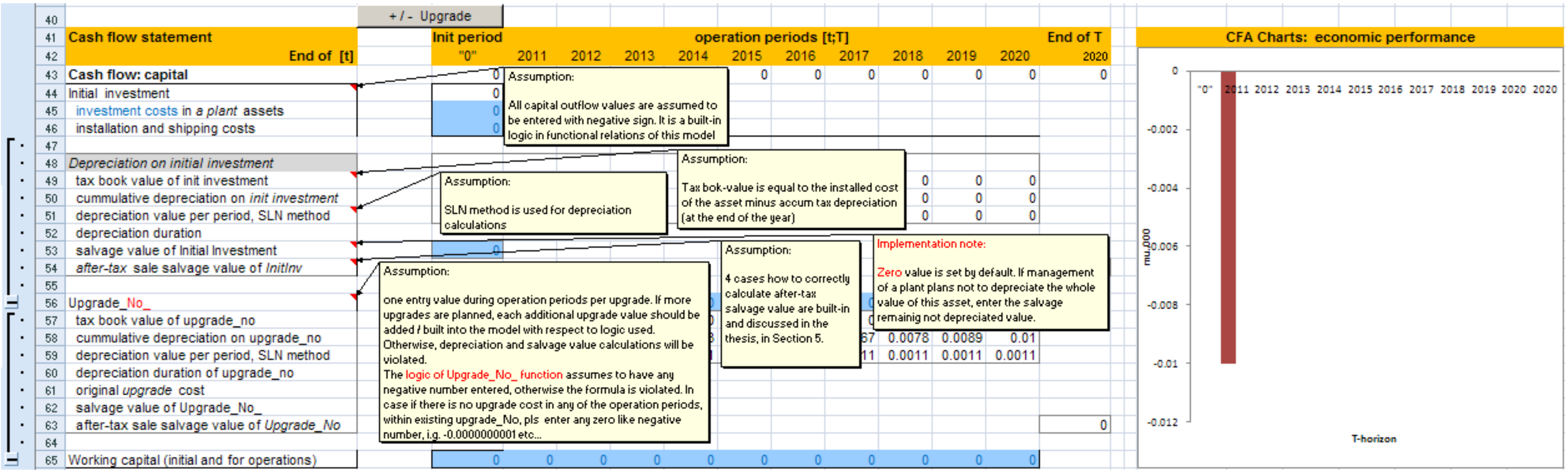
40		+ / - Upgrade									
41	**Cash flow statement**		**Init period**				**operation periods [t;T]**				**End of T**
42	**End of [t]**		"0"	2011	2012	2013	2014	2015	2016	2017	2017
43	**Cash flow: capital**		-2.82E+09	-281900000	0	0	0	0	0	0	281900000
44	Initial investment		-2.82E+09								
45	investment costs in *a plant* assets		-2.82E+09								
46	installation and shipping costs		0								
47											
48	*Depreciation on initial investment*										
49	tax book value of init investment		2.82E+09	2416285714	2.014E+09	1.611E+09	1.208E+09	805428571	402714286	0	
50	cummulative depreciation on *init investment*		0	402714286	805428571	1.208E+09	1.611E+09	2.014E+09	2.416E+09	2.819E+09	
51	depreciation value per period, SLN method		0	402714286	402714286	402714286	402714286	402714286	402714286	402714286	
52	depreciation duration										
53	salvage value of Initial Investment		0								
54	*after-tax* sale salvage value of *InitInv*										0
55											
56	Upgrade_No_		0	-0.01	0	0	0	0	0	0	
57	tax book value of upgrade_no		0	0	0	0	0	0	0	0	
58	cummulative depreciation on upgrade_no		0	0	0.0016667	0.0033333	0.005	0.0066667	0.0083333	0.01	
59	depreciation value per period, SLN method		0	0	0.0016667	0.0016667	0.0016667	0.0016667	0.0016667	0.0016667	
60	depreciation duration of upgrade_no										
61	original *upgrade* cost										
62	salvage value of Upgrade_No_		0								
63	after-tax sale salvage value of *Upgrade_No*										0
64											
65	Working capital (initial and for operations)		0	-281900000	0	0	0	0	0	0	

CFA Charts: economic performance

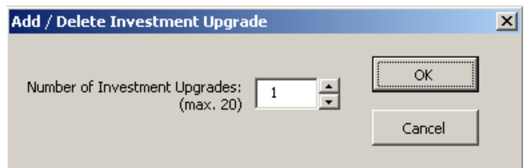


(b) Full view of Capital Flow

Figure 4: DDCFA design of Cash Flow module: Capital Flow



(a) Comments on Capital Flow



(b) Investment Upgrade submenu

Figure 5: DDCFA design of Cash Flow module: Investment Upgrade and Depreciation

Investment upgrades

Investment upgrades are designed to occur in any period t during the economic life span T of a Plant. It is designed to be added or removed from a system upon the request from the end-user. The investment upgrade as well as initial investment is subject to depreciation with a SLN method discussed in Subsection 4.1. It is the only depreciation method implemented into the tool. The depreciation on capital outflows is calculated in annualized and cumulative terms for each period $t, t \in T$. If the salvage value of investment is planned to be different from zero at the end of time horizon T, the corresponding entry fields for salvage value of initial investment and investment upgrades are to be filled manually. The computation of after-tax salvage value of initial investment and investment upgrade in period $t = T$ relies upon the tax book value of investment in that period (i.e. original investment cost less cumulative depreciation). The logic rules employed for computation of DDCFA after-tax salvage values are explained in Dayanada et al. (2002) and include several cases:

- if an investment asset is sold in period $t = T$ for a sum, which matches exactly the current written down value of the asset, there will be no loss or gain in the price for investment's salvage value. There is simply no basis to imply a corporate income tax for.
- if an investment asset is sold in period $t = T$ for a sum that is strictly less than the written down value of the asset in $t = T$, there will be a loss. Such a loss in operations is usually subject to tax reductions for exactly the same amount.
- if an investment asset is sold in period $t = T$ for a sum that is greater than the written down value of the asset in $t = T$ and less than original cost of installed investment, the standard corporate tax rate for operations is imposed only for value in-between written down value in period $t = T$ and original investment cost. The part of the sale amount up to written down value is considered as tax-free.
- if an investment asset is sold in period $t = T$ for a sum that exceeds the original investment cost, several tax rates are likely to be imposed. The part of the sale amount up to the original cost is subject to a standard corporate tax for operations, while the remaining sale amount is treated as capital gain. The latter is usually charged with an additional tax on the top of standard rate.

5.3.2 Cash Flow of operations

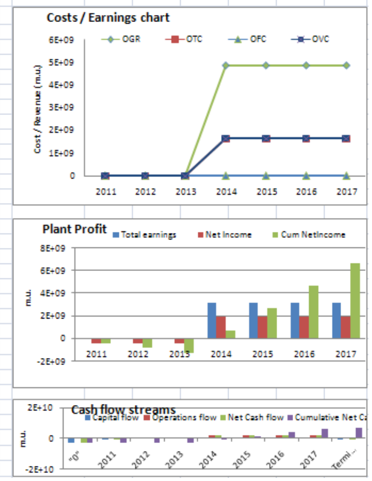
The Cash Flow Operations (CFO) represents the cash inputs and outputs, used accounting metrics to be operated on the GasMat Plant(s)production for each period $t, t \in T$ during the defined T-horizon. The design of this module is depicted in Figure 6 and implementation comments are available in the Figure 7.

The input data for CFO include sources of Gross Income and Total Costs. The Total Costs are split into several categories, including fixed non-investment costs (i.e. overhead costs) and variable operation costs. The latter was designed to include input costs of materials and operation costs of output products. For example, CFO of GasMat Steel Plant is represented in the Figure 6(a). The Plant generates income from selling Steel as composite product according to production design. The Income is a product of steel quantities by steel sale prices. The fixed non-investment costs are not specified, while variable costs include input costs of DRI, Steel scrap, kWh and operation costs of Steel. Subtraction of Total Costs from Gross Income results in Total Earnings (i.e. Profit) of the Plant. The profit maximization objective function of the optimization models such as product-mix, network flow models is often based on Total Earnings of the firm.

From the point of Investment Analysis the Total Earnings (or Profit) is a rough criterion and a subject for further investigation. The neglecting of the taxation, asset depreciation, loan servicing, etc.. lead to overestimating of the term Profit and Return on Investment. In this situation it is more precise to use Net Income and Free Cash Flow instead. The DDCFA CFO reflect these indicators in consecutive order.

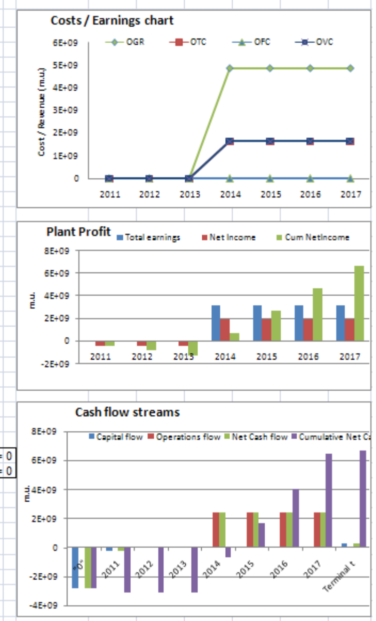
The computation of an intermediate non-GAAP metric such as Earnings Before Tax (EBT) is one way to obtain the value of Net Income in period $t, t \in T$. The EBT is obtained from Total Earnings less Depreciation for tangible assets, including depreciation on investment initial and investment upgrades, less Interest and Amortization for intangible assets. Afterwards, the Net Income is obtained from EBT by subtracting Tax Payable amount. The DDCFA tool also correctly treats the calculation of taxes, and only positive values of EBT are subject to Tax Payable over the T-horizon. Finally, the after-tax Cash Flow Operations values are obtained for each period $t, t \in T$ as follows. The previously subtracted Depreciation, Amortization and Interest are added back to the Net Income criterion.

Row	Cash flow statement		Init period			operation periods [t;T]				End of T
40		+ / - Upgrade								
41	Cash flow statement		Init period			operation periods [t;T]				End of T
42	End of [t]		"0"	2011	2012	2013	2014	2015	2016	2017 2017
66										
67	Cash flow: operations	+ / - "Income from"		0	0	0	2.381E+09	2.381E+09	2.381E+09	2.381E+09
68	"+" Gross Income (revenue)			0	0	0	4.868E+09	4.868E+09	4.868E+09	4.868E+09
69	income from Steel			0	0	0	4.868E+09	4.868E+09	4.868E+09	4.868E+09
70										
71	"-" Total costs			0	0	0	1.639E+09	1.639E+09	1.639E+09	1.639E+09
72	fixed non-investment costs			0	0	0	0	0	0	0
73	variable operation costs	+ / - "Variable costs"		0	0	0	1.639E+09	1.639E+09	1.639E+09	1.639E+09
74	input costs of DRI			0	0	0	1.09E+09	1.09E+09	1.09E+09	1.09E+09
75	input costs of Steel Scrap			0	0	0	0	0	0	0
76	input costs of kWh			0	0	0	228000000	228000000	228000000	228000000
77										
78	operation costs of Steel			0	0	0	321000000	321000000	321000000	321000000
79										
80	Total earnings (profit)			0	0	0	3.229E+09	3.229E+09	3.229E+09	3.229E+09
81	"-" Depreciation (tangible assets)			402714286	402714286	402714286	402714286	402714286	402714286	402714286
82	depreciation on initial investment			402714286	402714286	402714286	402714286	402714286	402714286	402714286
83	depreciation Upgrade_No_			0	0.0016667	0.0016667	0.0016667	0.0016667	0.0016667	0.0016667
84										
85	"-" Amortization (intangible assets)			0	0	0	0	0	0	0
86	"-" Interest			0	0	0	0	0	0	0
87	Earnings (profit) before tax, EBT			-402714286	-4.03E+08	-4.03E+08	2.826E+09	2.826E+09	2.826E+09	2.826E+09
88	"-" Tax payable			0	0	0	847885714	847885714	847885714	847885714
89	**Net Income**			**-402714286**	**-4.03E+08**	**-4.03E+08**	**1.978E+09**	**1.978E+09**	**1.978E+09**	**1.978E+09**
90	"+" Depreciation (tangible assets)			402714286	402714286	402714286	402714286	402714286	402714286	402714286
91	"+" Amortization (intangible assets)			0	0	0	0	0	0	0
92	"+" Interest			0	0	0	0	0	0	0
93										
94										
95	**Terminal Cash flow**									281900000
100										
101	**Net Cash flow = - CF capital + CF operations**		**-2.82E+09**	**-281900000**	**0**	**0**	**2.381E+09**	**2.381E+09**	**2.381E+09**	**2.381E+09**	**281900000**



(a) Reduced view of Flow Operations

Row	Cash flow statement		Init period			operation periods [t;T]				End of T
40		+ / - Upgrade								
41	Cash flow statement		Init period			operation periods [t;T]				End of T
42	End of [t]		"0"	2011	2012	2013	2014	2015	2016	2017 2017
66										
67	Cash flow: operations	+ / - "Income from"		0	0	0	2.381E+09	2.381E+09	2.381E+09	2.381E+09
68	"+" Gross Income (revenue)			0	0	0	4.868E+09	4.868E+09	4.868E+09	4.868E+09
69	income from Steel			0	0	0	4.868E+09	4.868E+09	4.868E+09	4.868E+09
70										
71	"-" Total costs			0	0	0	1.639E+09	1.639E+09	1.639E+09	1.639E+09
72	fixed non-investment costs			0	0	0	0	0	0	0
73	variable operation costs	+ / - "Variable costs"		0	0	0	1.639E+09	1.639E+09	1.639E+09	1.639E+09
74	input costs of DRI			0	0	0	1.09E+09	1.09E+09	1.09E+09	1.09E+09
75	input costs of Steel Scrap			0	0	0	0	0	0	0
76	input costs of kWh			0	0	0	228000000	228000000	228000000	228000000
77										
78	operation costs of Steel			0	0	0	321000000	321000000	321000000	321000000
79										
80	Total earnings (profit)			0	0	0	3.229E+09	3.229E+09	3.229E+09	3.229E+09
81	"-" Depreciation (tangible assets)			402714286	402714286	402714286	402714286	402714286	402714286	402714286
82	depreciation on initial investment			402714286	402714286	402714286	402714286	402714286	402714286	402714286
83	depreciation Upgrade_No_			0	0.0016667	0.0016667	0.0016667	0.0016667	0.0016667	0.0016667
84										
85	"-" Amortization (intangible assets)			0	0	0	0	0	0	0
86	"-" Interest			0	0	0	0	0	0	0
87	Earnings (profit) before tax, EBT			-402714286	-4.03E+08	-4.03E+08	2.826E+09	2.826E+09	2.826E+09	2.826E+09
88	"-" Tax payable			0	0	0	847885714	847885714	847885714	847885714
89	**Net Income**			**-402714286**	**-4.03E+08**	**-4.03E+08**	**1.978E+09**	**1.978E+09**	**1.978E+09**	**1.978E+09**
90	"+" Depreciation (tangible assets)			402714286	402714286	402714286	402714286	402714286	402714286	402714286
91	"+" Amortization (intangible assets)			0	0	0	0	0	0	0
92	"+" Interest			0	0	0	0	0	0	0
93										
94										
95	**Terminal Cash flow**									281900000
96	Sale salvage value of plant's *InitInv*									0 >= 0
97	Sale salvage value of *Upgrade_No*									0 >= 0
98										
99	Recovery of working capital									281900000
100										
101	**Net Cash flow = - CF capital + CF operations**		**-2.82E+09**	**-281900000**	**0**	**0**	**2.381E+09**	**2.381E+09**	**2.381E+09**	**2.381E+09**	**281900000**
102	net cash flow, termination is included into last t		-2.82E+09	-281900000	0	0	2.381E+09	2.381E+09	2.381E+09	2.381E+09	
103	cumulative Net Cash flow + CF terminal		-2.82E+09	-3.101E+09	-3.1E+09	-3.1E+09	-7.2E+08	1.661E+09	4.042E+09	6.424E+09	6.705E+09
104	*Non-discounted CFA techniques*									
105	Payback Period (PP)							4.3022894		
106	Profitability index	3.38								
107										



(b) Full view of Flow Operations

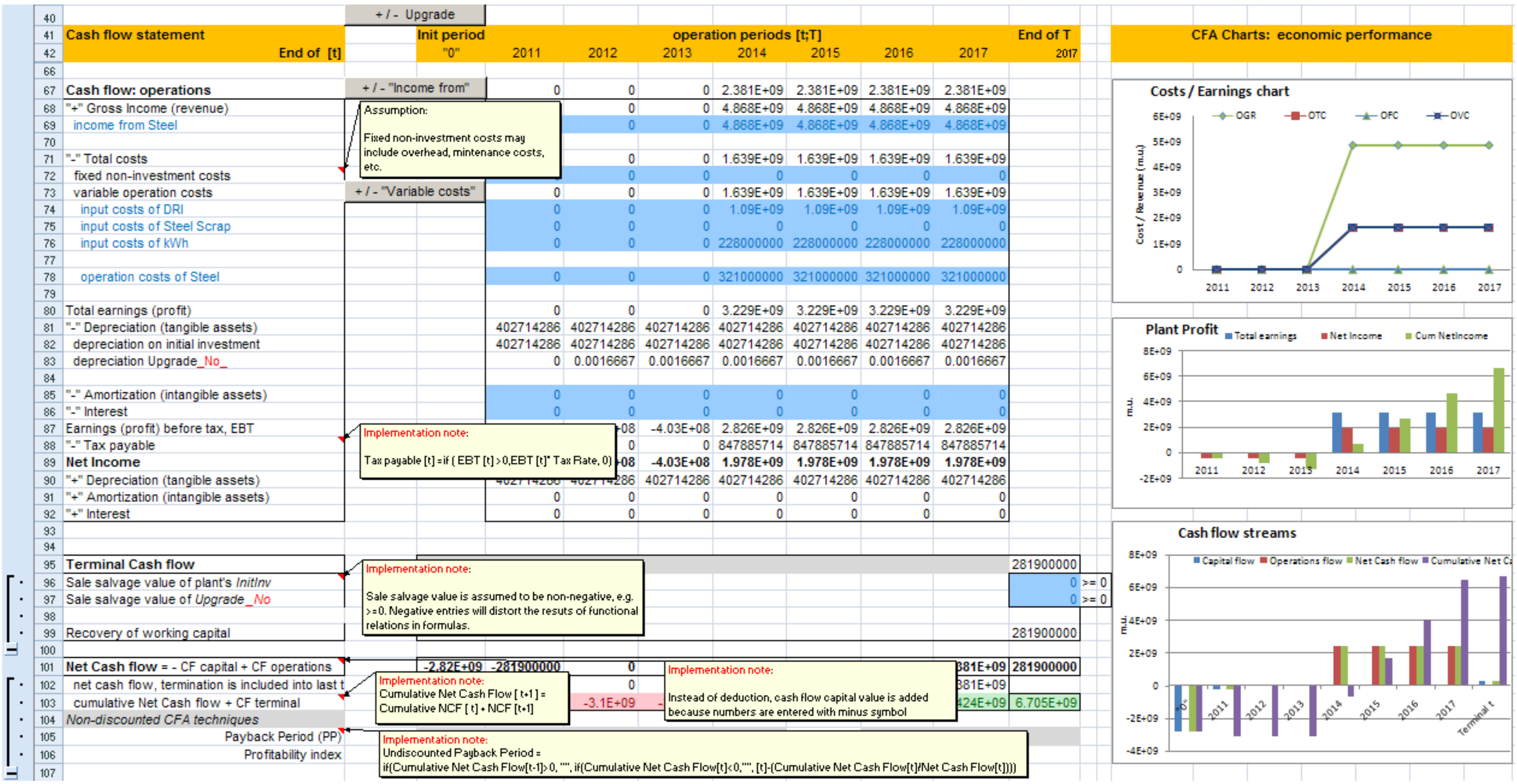
Figure 6: DDCFA design of Cash Flow module: Flow Operations

5.3.3 Terminal Cash Flow

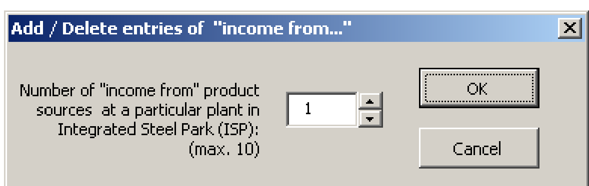
The DDCFA Terminal Cash Flow represents the summary of after-tax proceeds from sale of capital assets (i.e. salvage values) and recovery of Working Capital previously tied up in operations. Non-negativity requirements for sale prices of capital assets are assumed.

5.3.4 Net Cash Flow

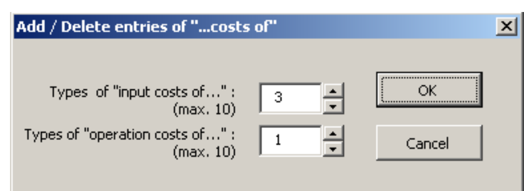
The Net Cash Flow (NCF) also known as Free Cash Flow simply represents the difference between after-tax Cash Flow Operations and Cash Flow Capital. The calculation of NCF is performed for each period $t, t \in T$. In addition, the assumption has been made that the Terminal Cash Flow value is to be added to NCF value in period $t = T$ as opposed to period $t = T + 1$. This is important from the point of discounting horizon, when obtaining Net Present Value of Investment into GasMat Plant(s).



(a) Comments on Cash Flow: operations Flow



(b) Income source submenu



(c) Variable costs source submenu

Figure 7: DDCFA design of Cash Flow module: Sources of Income and Variable costs

5.4 Investment Valuation Module

This subsection reasons about two different, but complementary groups of investment valuation methods.

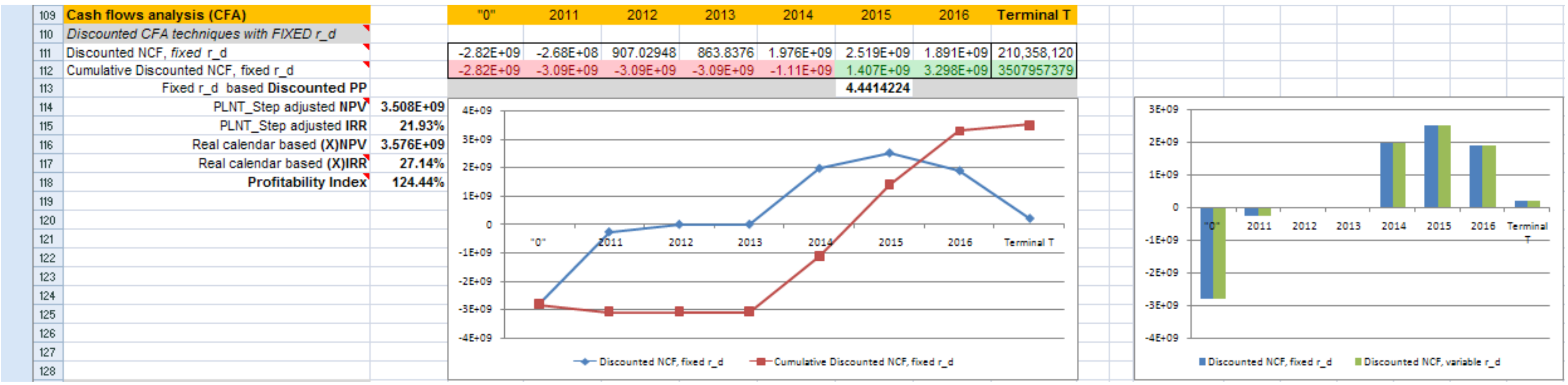
5.4.1 Discounted Cash Flow metrics: Net Present Value, Rate of Return

The conventional CFA analysis of Investment is based on following metrics. They are Discounted Payback Time, Net Present Value, Internal Rate of Return and Profitability Index. The entire set of criteria was implemented to perform valuation under different conditions including:

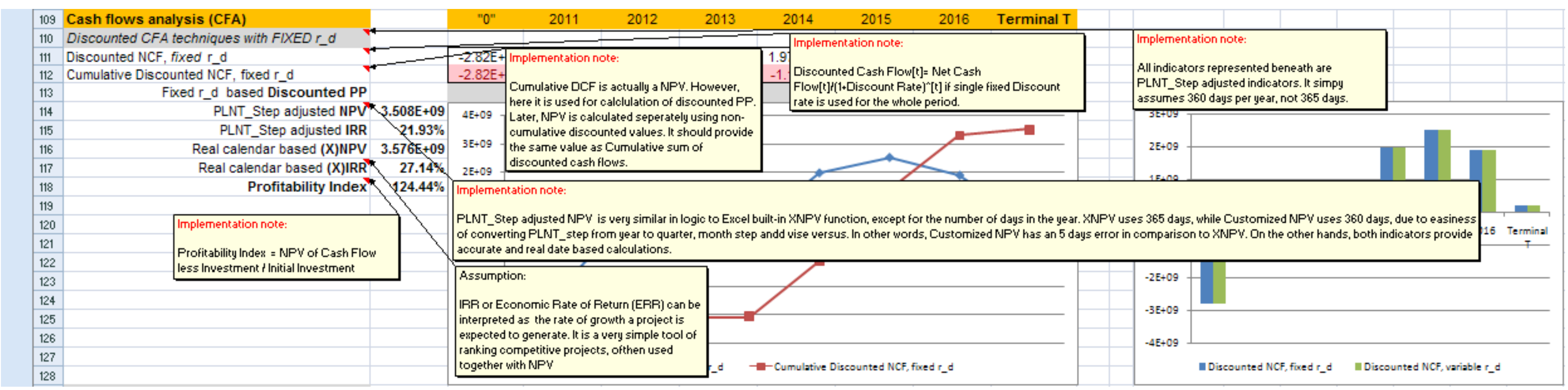
- usage of *fixed* discount rate for calculation of
  Discounted Net Cash Flow for each period $t, t \in T$
  Plant_step adjusted Net Present Value, Internal Rate of Return
  Plant_Step adjusted Discounted Payback Period and Profitability index
  Real Calendar based Net Present Value, Internal Rate of Return
- usage of *variable* discount rate for calculations of
  Discounted Net Cash Flow for each period $t, t \in T$
  Plant_step adjusted Net Present Value, Discounted Payback Period
  Plant_step adjusted Profitability index

The Plant_step adjusted timing strictly assumes 360 days in the year, while real calendar timing allows to use 364-365 days per year. So, the same indicator with Plant_step timing base (i.e. 30 days per month) will have a 4-5 day loss in value per year if compared with analogous metric but computed with respect to real calendar base.

The longer the planning T-horizon is, the bigger the difference in value between similar criteria becomes. The reason to use Plant_step timing is hidden in consistency of adjustment the planning horizon from yearly periods to 6 months, quarterly and monthly intervals regarding assumption of 360 days per each year and 30 days a month (i.e. minimal length of the period). In practice, every other month during the year consists of 31 days except for February, and the rest months consist of 30 days. In this thesis, the comparison of all implemented criteria is based on Plant_step timing base to provide consistency in results, unless stated otherwise. The exceptions are values of NPV and IRR computed both ways.

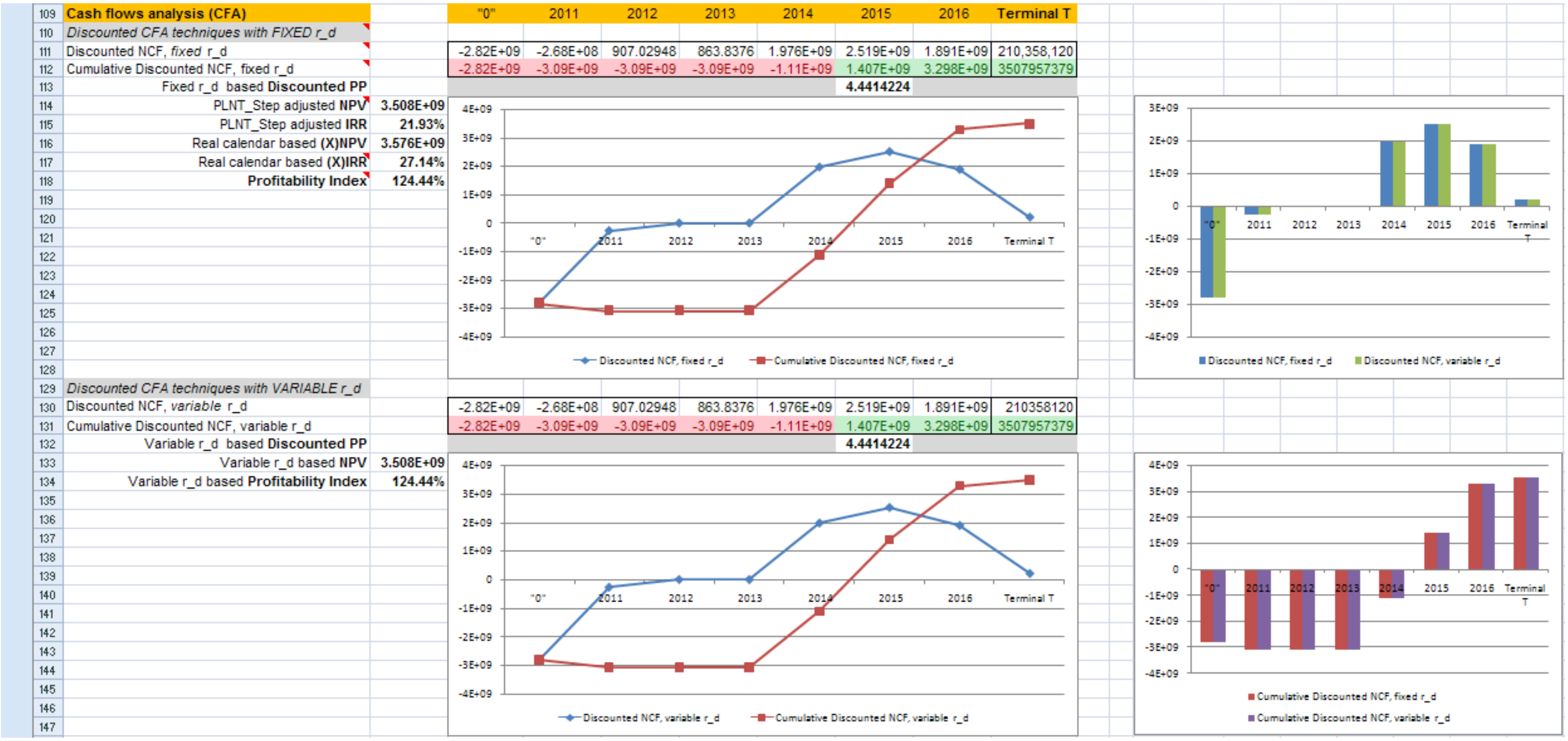


(a) DCFA metrics with fixed discount rate over T-horizon



(b) Comments on DCFA metrics with fixed discount rate

Figure 8: DDCFA Tool: Discounted CFA techniques with fixed discount rate

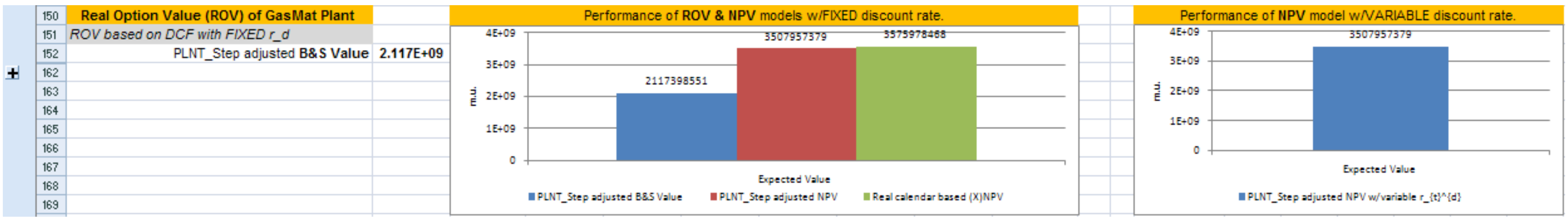


			"0"	2011	2012	2013	2014	2015	2016	Terminal T
109	**Cash flows analysis (CFA)**									
110	*Discounted CFA techniques with FIXED r_d*									
111	Discounted NCF, *fixed* r_d		-2.82E+09	-2.68E+08	907.02948	863.8376	1.976E+09	2.519E+09	1.891E+09	210,358,120
112	Cumulative Discounted NCF, fixed r_d		-2.82E+09	-3.09E+09	-3.09E+09	-3.09E+09	-1.11E+09	1.407E+09	3.298E+09	3507957379
113	Fixed r_d based **Discounted PP**							**4.4414224**		
114	PLNT_Step adjusted **NPV**	**3.508E+09**								
115	PLNT_Step adjusted **IRR**	**21.93%**								
116	Real calendar based **(X)NPV**	**3.576E+09**								
117	Real calendar based **(X)IRR**	**27.14%**								
118	**Profitability Index**	**124.44%**								
129	*Discounted CFA techniques with VARIABLE r_d*									
130	Discounted NCF, *variable* r_d		-2.82E+09	-2.68E+08	907.02948	863.8376	1.976E+09	2.519E+09	1.891E+09	210358120
131	Cumulative Discounted NCF, variable r_d		-2.82E+09	-3.09E+09	-3.09E+09	-3.09E+09	-1.11E+09	1.407E+09	3.298E+09	3507957379
132	Variable r_d based **Discounted PP**							**4.4414224**		
133	Variable r_d based **NPV**	**3.508E+09**								
134	Variable r_d based **Profitability Index**	**124.44%**								

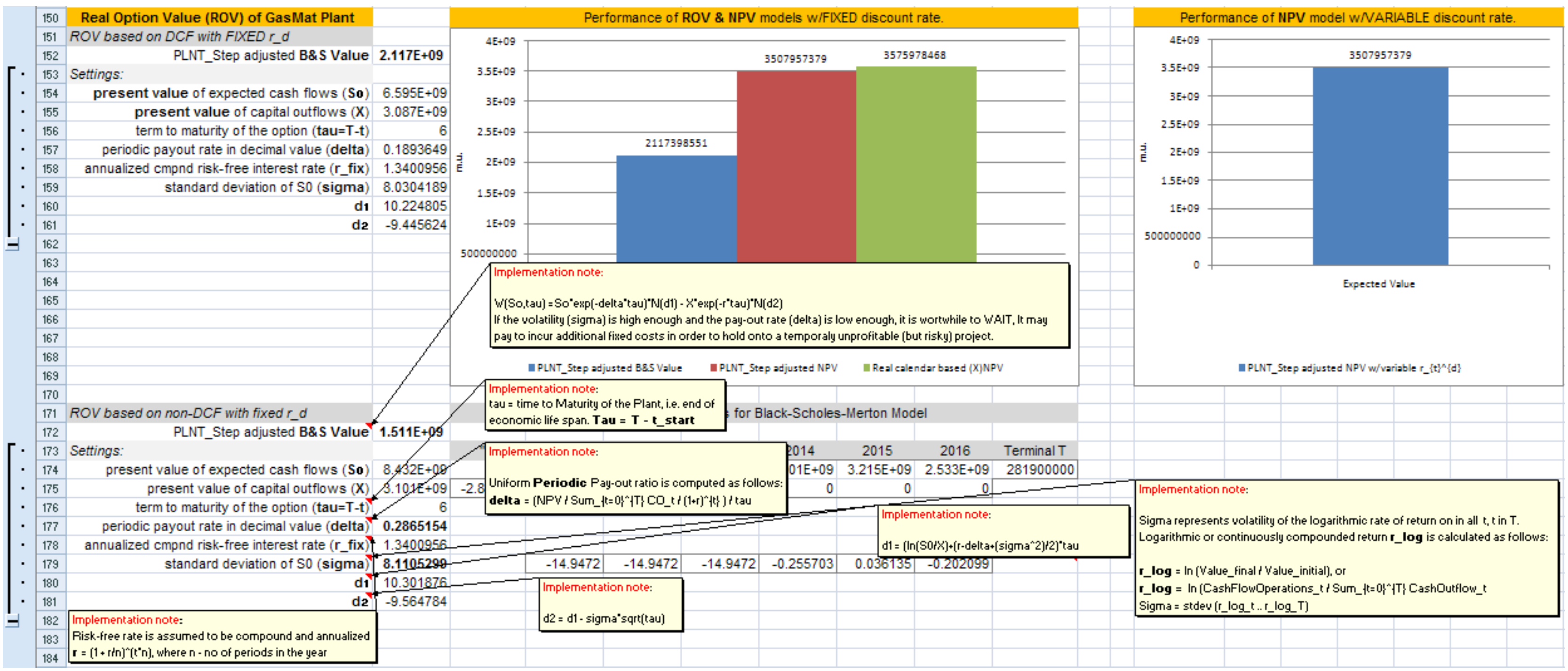
Figure 9: DDCFA Tool: Discounted CFA techniques with fixed and variable discount rate

5.4.2 Real Option Valuation: Black-Scholes criterion

The adopted version of Black-Scholes-Merton model for Real Investment (e.g. GasMat Plant) with timing option was implemented in DDCFA tool. It is depicted in the Figure 10. On the basis of length of planning T-horizon, the Black-Scholes-Merton model estimates the potential investment value regarding volatility of rate of return during T-horizon and pay-out rate. If the pay-out rate increases and the volatility of rate of return decreases over the length of T-horizon, there will be an increase in payback on Investment in GasMat Plant. With a low volatility of return rate, the B&S model usually outperforms the Net Present Value metric.



(a) Reduced view of Black-Scholes real option criterion



(b) Implementation comments on Black-Scholes real option

Figure 10: DDCFA Tool: Real Option Valuation techniques with fixed discount rate

6 Testing of DDCFA tool: Investment in GasMat Plant

6.1 Basics of scenario analysis

The complete analysis of GasMat Park should include several design scenarios. First scenario assume isolated analysis of every GasMat Plant of a chosen Park's design. In this case an assumption has been made that Industrial Park simple accomodates independent plants on its production site. The Plants maximize their own profit regarding prevailing market conditions and expectations. The suppliers of input materials (i.e. natural gas, iron ore) for GasMat Plants also act independently.

Second scenario increases complexity. It requires data and time-projections for all inputs and outputs of the GasMat Cluster. Here, the industrial park is analyzed as the group of *cooperating* plants with a central planning and distribution HQ Company. This scenario assumes also tight cooperation with suppliers of material suppliers (i.e. long-term contracts with affordable prices for natural gas and iron ore), internal cluster prices (e.g. lower, market equal and/or subsidized) for intermediate inside cluster products. Material and Cash Flows between plants, purchasing of inputs, sales of cluster market oriented products, sales of by-products for internal use and export are to be taken into cosideration.

The benefits and losses of being envolved into cluster for particular plant member can be estimated as follows. The independent plant performance criteria are compared with similar criteria of the same Plant under GasMat central planning scenario.

The GasMat cluster initially assumes that firing the raw natural gas is the cheapest and cleanest energy source from today's industry point. In its turn, DRI and Steel plant as key members of GasMat Park significantly rely on *affordable* gas price over the time. This assumption foresees a pricing strategy, which is subject to quantitative forecasting of gas price on the spot and/or contract market over the T-horizon.

The dynamic revision of GasMat production planning under changeable market conditions affects Steel Plant, which generates the most value added in the cluster, and the rest of Plants (i.e. DRI, Methanol, Power Plant, Natural Gas Processing plant, et cetera).

The three-step investment approach suggested in this master's thesis equally treats the GasMat Park and each of its Plants. For the purpose of demonstration DDCFA tool, the GasMat Steel Plant is considered. Albeit each Plant is important in GasMat value chain, the Steel Plant adds the largest value added to fine product sales. The Natural Gas Processing Plant is not considered.

In fact, the Steel plant is the easiest to analyze from the point of data availability. Every plant is subject to mass balance modeling based on simplified input-output relation. Most of the necessary input data (i.e. kWh, DRI and/or Steel scrap) and output data (i.e. fine crude steel) for the Steel plant was possible to collect from public sources and literature studies. In most other cases, the data is either confidential or for commercial distribution.

6.2 Input/Output projections for Steel Plant

The necessary time-series of Steel Plant inputs (i.e. DRI, Steel Scrap, kWh) and output (i.e. crude steel) for the forecasting activities has been collected recently. These data is represented in Appendix A. The primary analysis of past time-series has been executed, but future time-ptojections haven't been built yet. Due to rush work, accomodated efforts and time to the comprehensive problem related literature research, design of composite investment valuation approach, and most importantly development of DDCFA application, there was a lack of few extra days during the final stage of preparing the future price time-series demonstration instance.

Still, the DDCFA tool demonstrates the its full functionality but relaxing step one (i.e. forecasting) of the highly recommended investment valuation approach in this particular case. Instead, the static prices assigned to period $t = 1$ have been upgraded with minor growth factor over the T-horizon. In order to represent some volatility during the T-horizon, the built-in certainty equilivalent coefficients $b_{i,t}, b \in [0, 1]$ have been randomly generated in Excel and assigned to cash flow estimates for period $\forall t, t = 1, ..., T$.

6.3 Scenario settings for Steel Plant

The settings for Steel Plant Investment Appraisal can be grouped in several categories such as exogenous and endogenoues. Among exogenous factors are:

- The riskless interest rate is assumed as 5% per annum. The decision is based on the historical trend of U.S.Treasury LT Composite (>10yrs) depicted from figure 16 in

Appendix A. The premium risk (profit margin) was set to be 13% per annum. In total, the Steel Plant is subject to NPV testing with a Rate of Return of THIS% pee annum. The World Steel Association published the evidence on average Rate of Return on Investment in the Steel global insdustry, which is 19.6% as of year 2008. Their estimate proves the chosen rates for this demonstration

- The corporate tax rate is 30% for all periods in time horizon.

Endogenous production parameters in its turn include:

- The minimim life span of GasMat park is set to 10 years. The shortening of horizon increase the risk that a Plant with large initial investment expenses may generate little or negative Net Income by the end of 10 years. On the other hand there is a good chance to downpaid investment faster than with traditional 20-25 yrs terms.
- Initial capital outflow was assumed to occur at the end of period zero (beginning of the year 1). Construction investment upgrades were assumed to occur in years 2, 3 with 30%, 20%, of the initial capital outlay.
- Initial Working capital outflow accounts for 10% of initial capital outlay in year zero.

- Working capital tied up in the production was assumed to be recovered by the end of project's termination year 15.
- Overall construction period was assumed to take THREE years for the Steel Plant. Revenue generating cash flows were assumed to start in the year period 4.
- The Greenfiled Plant rarely starts with 100 per cent load afer commissioning. According to current scenario WGMO operational model assumes fixed capacity for all 15 years period. The attainment of projected capacity is gradually achieved through settings of production output volume per annum. It is manually reduced to be 50% of its maximal capacity in year 4, 75% in year 5 and 100% in years 6-15 inclusive.
- Straight Line Depreciation method is the only built-in option into DDCFA tool.
- Salvage values for the assets are not considered. Due to SLN depreciation method, whole original assets costs will be written off by the end of Year 10.

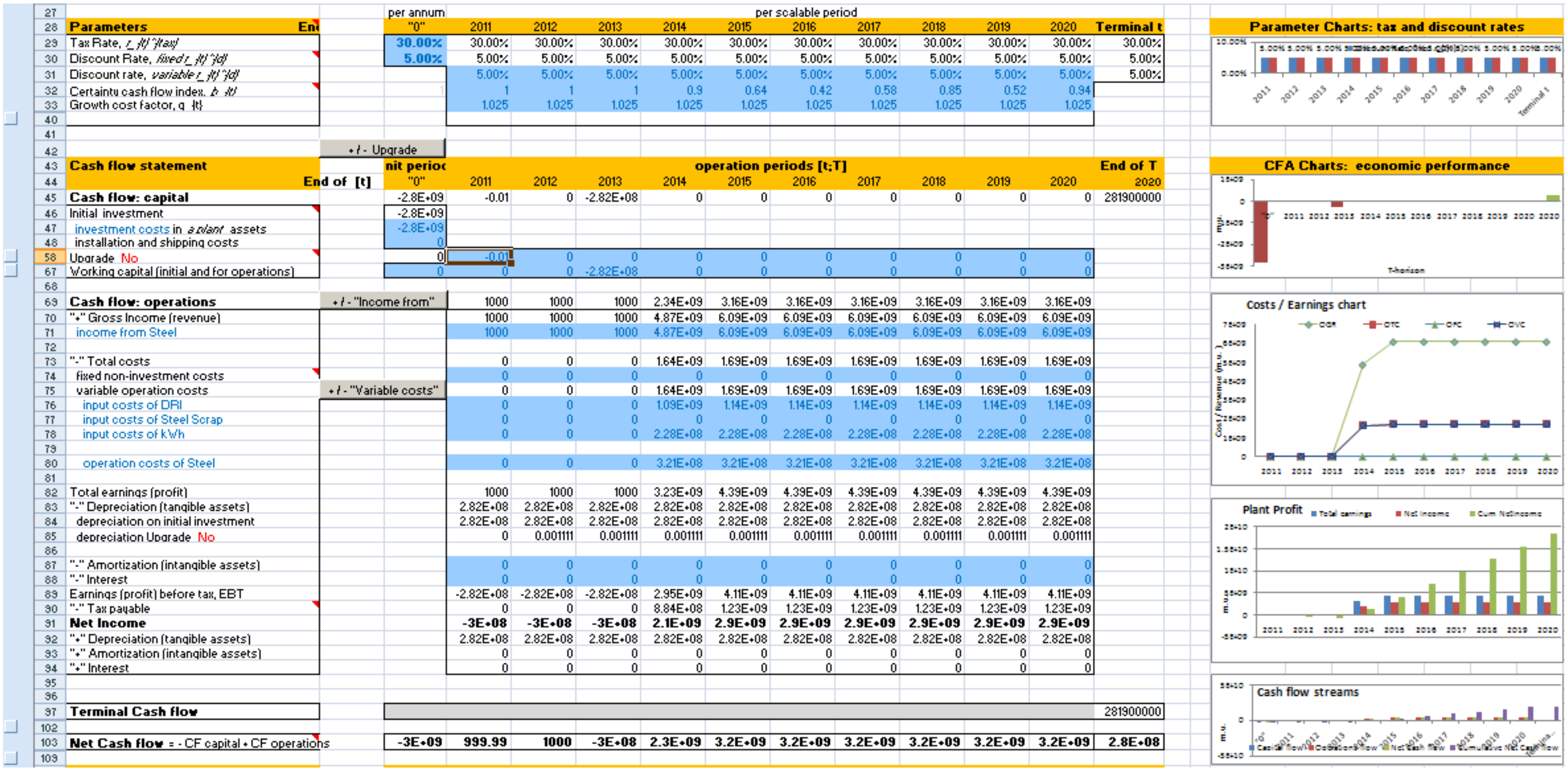
Since the GasMat Steel Plant is evaluated by WGMO Operational model-tool first, and then by DDCFA electronical tool, it is a good idea to prepare so-called inputs card for the entire planned horizon. The second name of WGMO Operational model is GasMat Network Flow model. These two names define the same model. Forecasted time-series values of commodity purchasing and sales prices, fixed and operational costs, minimal production output and maximal capacity values, growth values of operational costs over the time can be also stored together with other listed parameters. The summary of settings for Steel Plant under Isolated Operations is presented in Table 8. The latter can be used as the standardized template for input settings for any Plant in GasMat Park.

Table 8: Inputs Scenario card of Steel Plant

Settings for Plant i			**T-horizon, $t = 0, ..., T$**											
DDCFA Parameters	**Definitions**	**Units**	0	1	2	3	4	5	6	7	8	9	10	T=10
r_d	Discount rate in period	(per cent)		.05	.05	.05	.05	.05	.05	0.5	.05	.05	.05	.05
$b_{i,t}, b \in [0,1]$	CE coeff of cash flows $\forall t, t = 1, .., T$	(dec frac)		1	1	1	.90	.64	.42	.58	.85	.52	.94	.94
$g_{i,t}$	Growth cost factor $\forall t, t = 1, .., T$	(per cent)		.025	.025	.025	.025	.025	.025	.025	.025	.025	.025	.025
$r_{i,t}^{tax}$	Tax rate in period $\forall t, t = 1, .., T$	(per cent)		.3	.3	.3	.3	.3	.3	.3	.3	.3	.3	.3
$(wc)_{i,0}$	Initial working capital rate	(per cent)	.1											
$(wc)_{it}$	Additional working capital rate	(per cent)												
$Am_{i,t}$	Ammortization of Plant i, $t = 1, .., T$	($)												
$Int_{i,t}$	Interest in Plant i, $t = 1, .., T$	($)												
WGMO Parameters														
$(pp)_{DRI,t}$	Purchase price of commodity c in t	($ per ton)					172	172	172	172	172	172	172	172
$(pp)_{Scrap,t}$	Purchase price of commodity c in t	($ per ton)					290	290	290	290	290	290	290	290
$(pp)_{kWh,t}$	Purchase price of commodity c in t	($ per ton)					.57	.57	.57	.57	.57	.57	.57	.57
$(sp)_{Steel,t}$	Sale price of commodity c in period t	($ per ton)					767	767	767	767	767	767	767	767
$(cm)_i$	Productive maximal capacity of Plant i	(tons)	1000000											
$(cn)_i$	Productive minimal capacity of Plant i	(tons)												
$(pm)_i$	Min production requirement for Plant i in t	(tons)	1000000											
$(uic)_i$	Unit investment cost in Plant i	($ per ton)												
$(ifc)_i$	Investment fixed cost in Plant i	($)	80000000											
$(uoc)_i$	Operation unit cost in Plant i	($ per ton)					321	321	321	321	321	321	321	321
$(ofc)_i$	Operation fixed cost in Plant i	($)												
DDCFA Variables														
$ISC_{i,0}$	Installation & Shipping costs, at the end $t = 0$	($)												
$WC_{i,0}$	Working Capital outflow at Plant i in $t = 0$	($)	-2.82e+08											
$WC_{i,t}$	Working Capital outflow at Plant i in $t = 1, .., T$	($)												
$CO_{i,t}$	Investment outflow in Plant i in $t = 1, .., T$	($)												
Variables	**Adherent DDCFA-WGMO Variables**													
$IC_{i,0}$	Initial Investment Costs, at the end $t = 0$	($)	-2.82e+09											
$OTR_{i,t}$	Operation Total Revenue of Plant i, $t = 1, .., T$													
$OFC_{i,t}$	Operation Fixed Costs in Plant i, $t = 1, .., T$	($)												
$OIVC_{i,DRI,t}$	Operation Input Variable costs from c, $t = 1, .., T$	($)												
$OIVC_{i,scrap,t}$	Operation Input Variable costs from c, $t = 1, .., T$	($)												
$OIVC_{i,kWh,t}$	Operation Input Variable costs, $t = 1, .., T$	($)												
$OOVC_{i,steel,t}$	Operation Output Variable costs from c, $t = 1, .., T$	($)												

6.4 DDCFA results for Steel Plant

Calculation results are depicted in the Figure 11 and Figure 12. The testing revealed expected results. Due to the fact that real size values have been used, the output values seem to be large (i.e. in mln $). Overall the Investment seems profitable. Its payback period only 5 years, what gives at least 5 years of income ahead.



			per annum	per scalable period										
28	**Parameters**	End	"0"	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	**Terminal t**
29	Tax Rate, r_{t}^{tax}		**30.00%**	30.00%	30.00%	30.00%	30.00%	30.00%	30.00%	30.00%	30.00%	30.00%	30.00%	30.00%
30	Discount Rate, fixed r_{t}^{d}		**5.00%**	5.00%	5.00%	5.00%	5.00%	5.00%	5.00%	5.00%	5.00%	5.00%	5.00%	5.00%
31	Discount rate, variable r_{t}^{d}			5.00%	5.00%	5.00%	5.00%	5.00%	5.00%	5.00%	5.00%	5.00%	5.00%	5.00%
32	Certainty cash flow index, b_{t}		1	1	1	1	0.9	0.64	0.42	0.58	0.85	0.52	0.94	
33	Growth cost factor, q_{t}			1.025	1.025	1.025	1.025	1.025	1.025	1.025	1.025	1.025	1.025	
40														
41														
42		+/- Upgrade												
43	**Cash flow statement**		**init period**	**operation periods [t;T]**										**End of T**
44		**End of [t]**	"0"	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2020
45	**Cash flow: capital**		-2.8E+09	-0.01	0	-2.82E+08	0	0	0	0	0	0	0	281900000
46	Initial investment		-2.8E+09											
47	investment costs in a plant assets		-2.8E+09											
48	installation and shipping costs		0											
58	Upgrade No		0	-0.01	0	0	0	0	0	0	0	0	0	
67	Working capital (initial and for operations)		0	0	0	-2.82E+08	0	0	0	0	0	0	0	
68														
69	**Cash flow: operations**	+/- "Income from"		1000	1000	1000	2.34E+09	3.16E+09	3.16E+09	3.16E+09	3.16E+09	3.16E+09	3.16E+09	
70	"+" Gross Income (revenue)			1000	1000	1000	4.87E+09	6.09E+09	6.09E+09	6.09E+09	6.09E+09	6.09E+09	6.09E+09	
71	income from Steel			1000	1000	1000	4.87E+09	6.09E+09	6.09E+09	6.09E+09	6.09E+09	6.09E+09	6.09E+09	
72														
73	"-" Total costs			0	0	0	1.64E+09	1.69E+09	1.69E+09	1.69E+09	1.69E+09	1.69E+09	1.69E+09	
74	fixed non-investment costs			0	0	0	0	0	0	0	0	0	0	
75	variable operation costs	+/- "Variable costs"		0	0	0	1.64E+09	1.69E+09	1.69E+09	1.69E+09	1.69E+09	1.69E+09	1.69E+09	
76	input costs of DRI			0	0	0	1.09E+09	1.14E+09	1.14E+09	1.14E+09	1.14E+09	1.14E+09	1.14E+09	
77	input costs of Steel Scrap			0	0	0	0	0	0	0	0	0	0	
78	input costs of kWh			0	0	0	2.28E+08	2.28E+08	2.28E+08	2.28E+08	2.28E+08	2.28E+08	2.28E+08	
79														
80	operation costs of Steel			0	0	0	3.21E+08	3.21E+08	3.21E+08	3.21E+08	3.21E+08	3.21E+08	3.21E+08	
81														
82	Total earnings (profit)			1000	1000	1000	3.23E+09	4.39E+09	4.39E+09	4.39E+09	4.39E+09	4.39E+09	4.39E+09	
83	"-" Depreciation (tangible assets)			2.82E+08	2.82E+08	2.82E+08	2.82E+08	2.82E+08	2.82E+08	2.82E+08	2.82E+08	2.82E+08	2.82E+08	
84	depreciation on initial investment			2.82E+08	2.82E+08	2.82E+08	2.82E+08	2.82E+08	2.82E+08	2.82E+08	2.82E+08	2.82E+08	2.82E+08	
85	depreciation Upgrade No			0	0.001111	0.001111	0.001111	0.001111	0.001111	0.001111	0.001111	0.001111	0.001111	
86														
87	"-" Amortization (intangible assets)			0	0	0	0	0	0	0	0	0	0	
88	"-" Interest			0	0	0	0	0	0	0	0	0	0	
89	Earnings (profit) before tax, EBT			-2.82E+08	-2.82E+08	-2.82E+08	2.95E+09	4.11E+09	4.11E+09	4.11E+09	4.11E+09	4.11E+09	4.11E+09	
90	"-" Tax payable			0	0	0	8.84E+08	1.23E+09	1.23E+09	1.23E+09	1.23E+09	1.23E+09	1.23E+09	
91	**Net Income**			**-3E+08**	**-3E+08**	**-3E+08**	**2.1E+09**	**2.9E+09**	**2.9E+09**	**2.9E+09**	**2.9E+09**	**2.9E+09**	**2.9E+09**	
92	"+" Depreciation (tangible assets)			2.82E+08	2.82E+08	2.82E+08	2.82E+08	2.82E+08	2.82E+08	2.82E+08	2.82E+08	2.82E+08	2.82E+08	
93	"+" Amortization (intangible assets)			0	0	0	0	0	0	0	0	0	0	
94	"+" Interest			0	0	0	0	0	0	0	0	0	0	
95														
96														
97	**Terminal Cash flow**													281900000
102														
103	**Net Cash flow** = - CF capital + CF operations		**-3E+09**	**999.99**	**1000**	**-3E+08**	**2.3E+09**	**3.2E+09**	**3.2E+09**	**3.2E+09**	**3.2E+09**	**3.2E+09**	**3.2E+09**	**2.8E+08**
109														

Figure 11: DDCFA Tool: Cash Flow Analysis of Steel Plant test instance

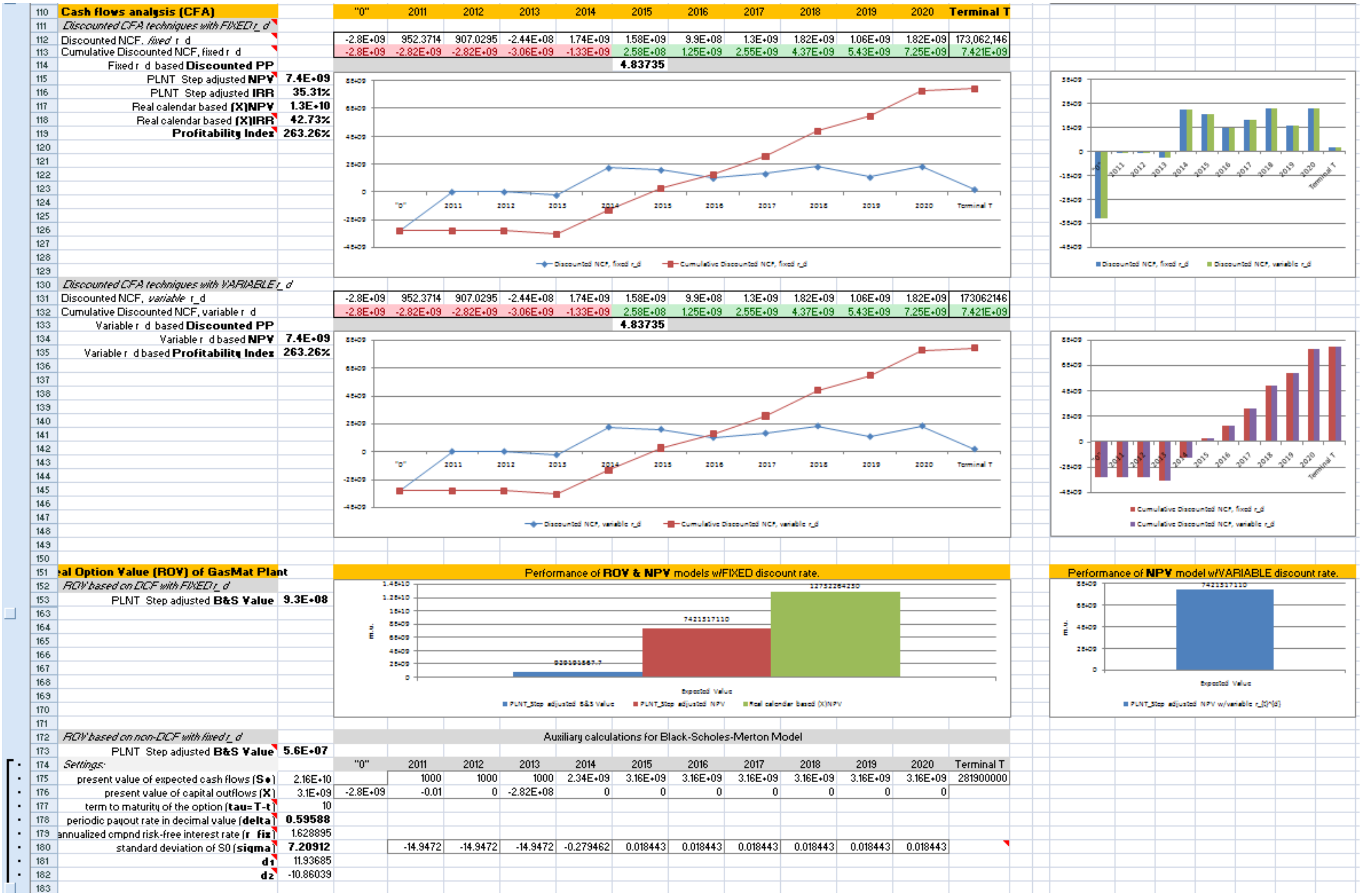


Figure 12: DDCFA Tool: Performance Critera of Steel Plant test instance

7 Conclusions and future work

The topic and direction of research for this master thesis was mutually discussed between me, my supervisor and her colleagues at SINTEF, Applied Economics and Operation Research during the guest visit to SINTEF, Trondheim in December 2008. It was then agreed that this thesis should aim at contributing to analysis of Cash Flows of GasMat facilities. The reason for that was simple. Having started the project in spring 2008, most of the attention at SINTEF was given to economic modeling of a complex Mass Balance Product-mix model and Network Flow model for running several metallurgical facilities simultaneously. Since there is also a need for Investment Valuation of each Plant in the cluster, the untouched yet area of modeling was offered as the topic for the master thesis.

This thesis examines different techniques of investment analysis and combines several into designed three-step investment valuation approach. By applying principles and techniques of quantitative time-series analysis, linear modeling of production processes, Capital Budgeting and Real Option Theory, the composite framework for investment valuation was introduced. The thesis work has been primarily focused on the development of a Generic DDCFA Investment valuation tool, which computes the after-tax-time value of capital investment throughout long-term project horizon. Regarding GasMat project, the interactive Dynamic Discounted Cash Flow Analysis tool is considered as the final step of the suggested composite investment valuation approach. Both the tool and the framework should assist in carrying out either positive or negative investment decision upon each and every Plant in the GasMat Park with respect to its profitability and changeable business environment over the time.

Benefits of three-step investment valuation framework

The idea to introduce a composite investment valuation approach for GasMat Plant(s) appeared during conducting a literature research from three different angles.

First, the evidence of project design and investment practices in the steel industry was being collected. For my part, it was a totally new area for me and there was a need to get a grip on specifics of economic valuation of metallurgical facilities in the steel industry. Since the steel industry is a processing industry, real investments are mainly concerned about investment in production capacities including building Greenfield facilities and/or expansion productive capacities of existing industrial facilities. Several authors used term

Investment Design bearing in mind the choice of timing, location, size of capacities, technology and product mix. The majority of publications focus on investment in productive capacity, leaving the analysis of cash flows to economists and financial analytics. Bearing in mind, that the operation model is being developed at SINTEF, the decision was taken not to dig into operation model, but attack the problem from investor point of view.

Second, the Capital Budgeting theory explains how to evaluate industrial investments from the point of Cash Flow Analysis. It was shown in this thesis that a typical analysis of investment considers usage of standard Discounted Cash Flow Analysis metrics, when evaluating the Project's Cash Flows. They are Net Present Value, Rate of Return, Payback Period, etc... Even if the Cash Flow Statement is simplified it is important to adjust periodic cash inflows from an investment with corresponding tax rate, since taxes reduce the Net Income metric significantly, and should not mislead the results. The purpose of the thesis was to develop an investment valuation tool, but not a precise accounting tool regarding Norwegian legislation. The advanced valuation methods of large industrial investments came from Real Option theory. Both standard and advanced valuation techniques are discussed in the Subsection 3.3 of conducted literature research. In fact, it was argued that additional usage of Real Option Valuation metrics often improves the results.

Finally, it was considered that the efficient way to reduce uncertainty in valuation of investment in the long term is to use forecasting methods of time-series data, including prices and quantities of input materials and output products. There are several market oriented price strategies to keep in mind. One possibility is to follow long-term contracts with relatively fixed prices for a contract period. Another possibility is to work on the spot market, which is more uncertain and volatile in product prices. As opposed to standard contract, an option-contract is another alternative. All three strategies require different methods of time series forecasting of product prices.

Benefits of developed DDCFA tool

The main advantage of developed Dynamic Discounted Cash flow Analysis Tool is the employment of both standard and advanced criteria. The implemented Net Present Value (NPV) metric gives the evidence for the break even Internal Rate of Return (IRR) and economic effect of using desirable Rate of Return on Investment (i.e. riskless IRR plus premium rate for the risk). It is argued that assumed Return on Investment rate is validated whether the NPV of investment is still going to be profitable, while the Black-Scholes metric justifies whether the considered investment horizon is riskless enough to generate a certain level of Net Present Value.

The Black-Scholes model for real projects extends the evaluation of Net Present Value of investment regarding timing option. This criterion estimates the Net Present Value of Investment from the point of volatility of expected cash flows throughout horizon, and length of the considered economic life span. The timing option affects variance of the NPV. When the expected cash inflows from investment opportunity (i.e. the option to consider Plant operation for a certain period) are worth more than expected capital outflows connected with investment, the decision to fix or extend initial T-horizon is justified. If the volatility of rate of return on investment over horizon is high enough and the periodic pay-out rate is low enough, the decision to consider longer T-horizon becomes more risky.

Another advantage of this tool is its generic application for real investments in any production areas where exist cash inflow stream and capital outflow stream over the planning horizon of investment. Moreover, the tool can be used not only for ex-ante analysis, but also for post investment period regarding periodic monitoring of actual cash flows versus past forecasts.

Section 6 demonstrates the results of investment valuation in hypothetic GasMat Steel Plant. They consist of ten-years market projections of Plant's major inputs (i.e. price forecasts of DRI, Steel Scrap, kWh), steel outputs (i.e. price forecasts for crude steel), and potential in import substitution of composite steel products in Norway. The Plant's multiperiod input cash flows, operational flows and revenue stream are generated and exported from WGMO Mass Balance operational model into DDCFA tool for analysis. Comments on Discounted Cash Flow metrics and Black-Scholes-Merton criterion are given.

Future work

Maximizing an overall profit with a fair sharing mechanism is among major modeling challenges in a cluster that is very dependent on internal prices and the organization of the relationships between the integrated steel plant and other facilities of the cluster. One of the ways to implement a fair profit sharing mechanism is to introduce contract specified compensation installments from major revenue holders (e.g. DRI and Steel Plant in GasMat Park) to other units of the cluster. Such a mechanism works perfectly if an option contract scheme is used between participants. Though, it requires taking into consideration the decisions to be made under market uncertainty.

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Appendix A Time series inputs for GasMat Steel Plant

Sources of exogenous parameters

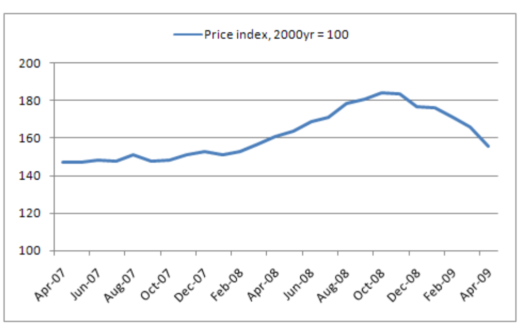
The following time series inputs are subject to analysis by means of quantitative techniques discussed in Subsection 3.4.

Crude Steel and DRI

It is obvious that usage of forward contracts (i.e. ahead month, quarter, one year forward, etc.) for analysis instead of relying on spot prices for inputs is the only option for day-to-day operation, mid- and long-term stable production planning. It is a conventional practice to sell large volumes of output products with respect to the mid- and long-term contracts rather than fluctuating spot price for products with limited liquidation. Arbitrage operations are not considered. It is necessary to have a portfolio of orders to avoid operation disruption and low capacity load.

Norwegian time series statistics

The domestic prices and consumption of iron and steel in Norway are depicted in Figure 13. The collected data represents 25 last months of year 2007, 2008 and 2009.



(a) Iron and Steel Price indexes, year 2000 = 100

(b) Steel Price indexes in the construction industry

Figure 13: Iron and Steel Price Indexes 2004-2009. Source: Norwegian Steel Association, Statistisk sentralbyrå

Table 9: Norwegian price indexes for the iron and steel (SITC) 2007-2009. Year 2000 = 100. Source: Statistisk sentralbyrå

Date	Price index	Date	Price index	Date	Price index
Apr-07	146.9	Jan-08	150.9	Oct-08	184.3
May-07	147.1	Feb-08	152.6	Nov-08	183.9
Jun-07	147.9	Mar-08	156.8	Dec-08	177
Jul-07	147.7	Apr-08	160.8	Jan-09	176
Aug-07	151.2	May-08	163.6	Feb-09	170.8
Sep-07	147.7	Jun-08	169	Mar-09	166
Oct-07	148	Jul-08	171	Apr-09	155.8
Nov-07	150.9	Aug-08	178.7		
Dec-07	152.7	Sep-08	180.6		

The analysis of potential of Norwegian import substitution of steel products gives an evidence of the minimal production capacities for both DRI and Steel Plants in GasMat necessary to satisfy at least domestic needs in steel. Norwegian export[1] source data in the form of Standard International Trade Classification (SITC) is presented in Table 10, Table .

Table 10: Norwegian exports by group of the SITC, Mln kroner/€. Source: Statistisk sentralbyrå

Item	Jan-Mar 2008 (1Q)			Jan-Mar 2009 (1Q)		
	Quantity, t.	Value, kr.	Value, €	Quantity,t.	Value, kr.	Value, €
67. Iron & Steel	n/a	4 011	457.87	n/a	2 625	299.65
671 Pig iron, iron sponge,granulated iron, steel and ferro alloys	n/a	2 189	249.88	n/a	1 228	140.18
672 Semi-finished products of iron or steel	26 412	169	19.29	28 553	185	21.11
673 Flat-rolled products of iron or non-alloy steel, not plated or coated	13 335	107	12.21	13 514	118	13.47
674 Flat-rolled products of iron or non-alloy steel, plated or coated	31 300	192	21.91	5 582	39	4.45
675 Flat-rolled products of alloy steel	7 681	75	8.56	909	16	1.82
676 Rods, profiles of iron and steel	123 598	569	64.95	97 878	430	49.0
677 Rails, blades, etc.. of iron or steel	12	1	0.11	230	2	0.22
678 Wires of iron or steel	234	4	0.45	381	11	1.255
679 Hollow profiles, pipes and fittings of iron or steel	27 912	705	80.47	21 047	596	68
Total	230 484	4 011	457.87	168 094	2 625	299.65

WGMO Operational model assumes many factors such as productive capacities, given demands to be fixed over the time, but not the prices for commodities. It was agreed that predictable behavior of commodities purchasing and selling prices are the most critical for

[1] 1€=8.76 as of 12/05/09

the investment analysis, since GasMat Park should consume a vast amount of Natural Gas, Iron Ore, kWh per annum, etc. Every Plant has the maximal installed capacity parameter. So does the DRI, Steel Plant. The capacity estimate is often based on judgement of supplies fixed long-term contracts. If it exceed the market requirement the Plant can face the overproduction of commodities (steel, HBI, etc.) along with falling prices it will negatively affect the Plant.

One way to hedge again the loss of overproduction and over investment in excessive capacity is to upgrade capacities over the time when a guaranteed demand is going to grow, but not building it at once. Since, the idea to set up GasMat Park is based on assumption of affordable natural gas price for domestic consumption, it will make sence to have minimal capacities at Import level of DRI/HBI, range of steel products. In practice, there is a growing historical demand for DRI/HBI, Steel products, kWh, etc. which secures hign capacities from being under occupancy.

Unfortunately, there is not much statistical time-series of DRI, Steel is available from Norwegian state sources. Often, the partially available data is combined with other articles according to SITC rules. For the forecasting purpose, it is much more preferable to work with long time-series. On the contrary, Global sources of aggregated prices and quantities of DRI/Steel offer longer time-series for analysis, and thus more benefitial for forecasting analysis.

Global time series statistics

In general, the crude steel is converted into carbon steel, stainless steel, tools steels, utilitarian steels, specific steels, nickel alloys, micro-alloyed steel, alloy steels, general steels and duplex steel. Two main groups are carbon and stainless steels. The investigation of global time series is limited to carbon steel products composite prices and indexes. They are most common and cheapest among other steels. The composite steel product includes Hot Rolled Coil, Hot Rolled Plate, Cold Rolled Coil, HD Galvanized Coil, Elector Zinc Coil, Wire Rod, Structural Sections and Beams, Rebar and Merchant bar.

Power

Real time-series price of MWh have been obtained from The Nord Pool ASA () and Nord Pool GAS AS () and represent Scandinavian Power and Gas Market measured in €/MWh. There are several main data streams that are depicted in Figure 14 and Figure 15, including spot price quotes with a month time-series log, nearest quarter and year forward contracts with a year time-series log. The forecasting of MWh in this thesis refers to this data.

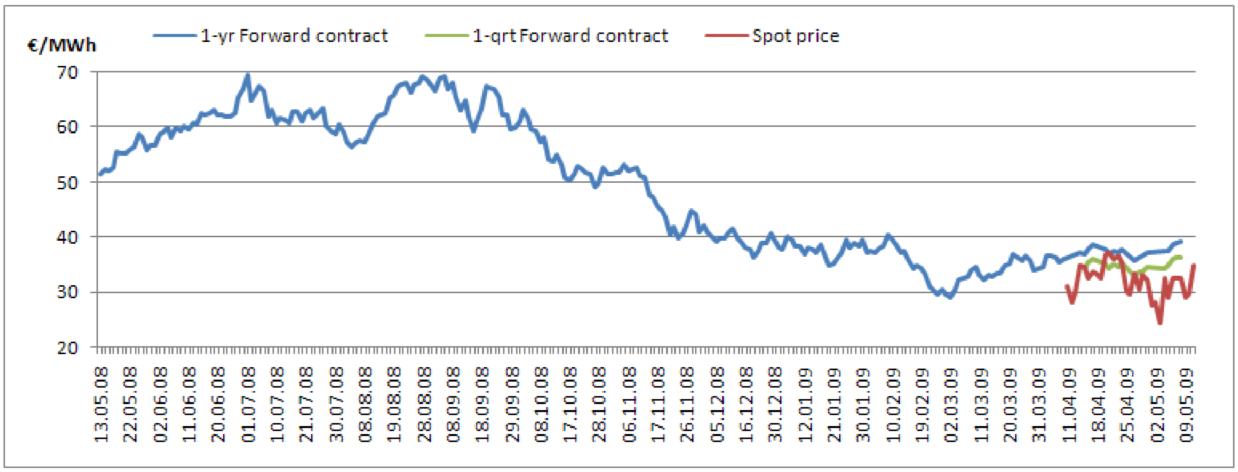


Figure 14: The Norwegian time-series quotes for Power, €/MWh. Source: Nord Pool ASA

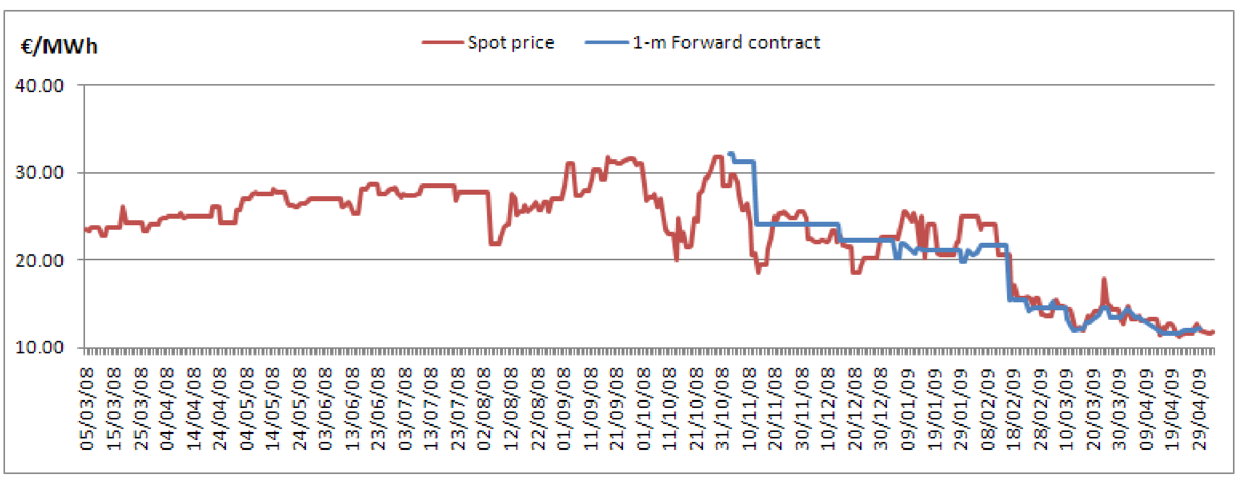


Figure 15: The Norwegian time-series quotes for Gas, €/MWh. Source: Nord Pool Gas AS

The evidence of existing relevant forecasts of future electricity prices has been seen in several recent studies. For example, Thollander et al. (2008) cites the study by Melkerson M.

(dish) indicating that electricity prices in Sweden are forecasted to to be around 80€/MWh Monday-Friday 6am-6pm, and about 44€/MWh during rest of the week. It includes the price estimate of CO_2 emission, which is about. 10€/ton. This is equivalent to 3-4€per MWh. The similar results have been reported in ECON centre for economic analylsis AB (dish).

Sources of endogenous parameters

Investment costs connected with Steel Plant

The conducted literature research has depicted several valuation methods and absolute estimates on capital investments in the steel processing industries in 3.2.3. For example, the capital costs of Finnish Steel mill are discussed in Collan (2004), including starting date, construction term, operation term up to day, initial capital expenses, costs of upgrades and capacity expansions. Unfortunately, there is little evidence of such estimates for a natural gas-fired DRI and Steel plant regarding different production volumes. This information is often protected by the owners. Thus, a scenario of investment parameters has been created for the testing of DDCFA model.

Calculations in Kekkonen et al. (2006) testify that a 2.6Mt Steel plant requires investment costs of 150M€, loan period 15 years and interest rate 10% per annum. Dutta (2008) gives an evidence of production capacities and investment program at Rashtriya Ispat Nigam Ltd. (RINL), which is a port based 3.6Mtpa Indian steel plant. It generated a sales turnover of US$ 2.32 bn. and net profit of US$ 0.432 bn. by producing 3.32 MT of crude steel within 2007-2008, mainly long steel products. Its long-term investment program considers expansion to 6.3 MT per annum of crude steel, which is under progress. An expansion to 8.5 MT per annum was planned to be completed by 2012. Third and fourth stages would take the capacity to 16 MT per annum.

Having identified some empirical evidence for production capacities and investment costs of a typical Steel Plant, it is now possible to validate the approach of calculation capital costs discussed in Subsection 3.2.3. It is the only possibility to estimate capital outflow of GasMat Steel Plant, when only its capacity is known. In this case 2.0 MT per annum of steel production was assumed.

DDCFA model parameters

Discount rate

The discount rate for the GasMat Steel Plant as industrial investment with a long lifespan (>10 years)a flat annual rate is considered. It is the most popular business practice to consider a nominal Long-Term Composite Rate on U.S. Treasury Bonds (>10 years) as the risk-free discount rate. Its time series are depicted in Table 11.

Table 11: Daily U.S. Treasury Long-Term Composite Interest Rates

Date	LT CMT (>10 yrs)	LT CMT (>10 yrs)	Treasury 20-yr CMT
03/01/2000	6.87%	%	6.94 %
03/01/2001	5.69%	%	5.62 %
03/01/2002	5.79%	%	5.83 %
03/01/2003	4.92%	%	5.03 %
02/01/2004	5.05%	%	5.21 %
03/01/2005	4.71%	%	4.84 %
03/01/2006	4.58%	%	4.62 %
03/01/2007	4.83%	%	4.85 %
03/01/2008	4.33%	%	4.41 %
05/01/2009	3.25%	2.56%	3.37 %
05/04/2009	3.94%	2.54%	4.11 %

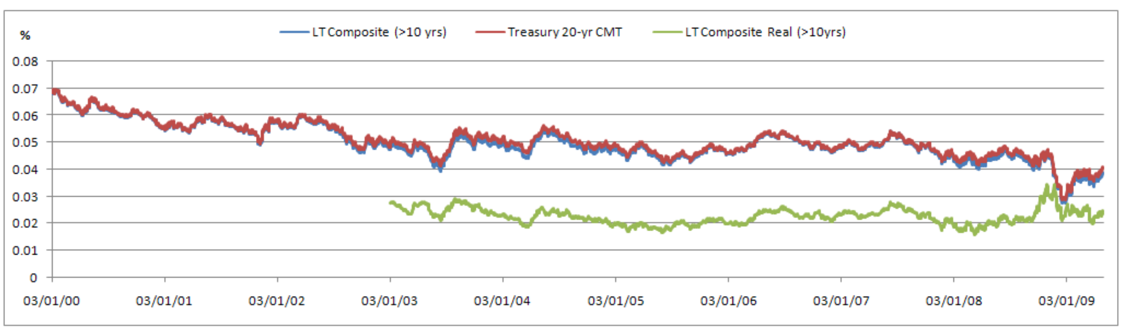


Figure 16: Daily U.S.Treasury Long-Term Composite Rate trend

The same data [2] is visualized in the Figure 16. The time series are calculated as the unweighted average of bid yields on all outstanding fixed-coupon bonds neither due nor callable in less than 10 years. 16.

[2]Source: U.S.Department of the Treasury.

Optimal time horizon

The option to build an industrial plant, expand the production capacities under current technological process, and change of technology used is an investment issue. Often the decision to expand or upgrade production capacities is taken after the expiry of a 7-10 years period, whereas the economic life of assets and implemented technological process is about 15 to 20 years. The construction period of an integrated steel plant takes from 3 to 5 years, while break-even operation term (i.e. payback period) varies from 5 to 7 years regarding market conditions. For example, Collan (2004) studied the case of large investment (i.e. FIM 1,56 billion) in the Coking Plant for own requirements at Finnish Integrated Steel Plant[3]. The author's findings are represented in the Table 12. Calculations in Kekkonen et al. (2006) considered a 2.6Mt/year Steel plant, investment costs amounting to 150M€, loan period of 15 years and 10% interest rate.

Table 12: Timing and Investment in Coking Plant, 1984-2004. Rautaruukki Oyj, Finnmark

Investment	**Planning & Construction**			**Operation w/o upgrades**			**Capacity**		**Requirement**
	yos	term	costs an.	yos	term	income an.	an. change	an. total	an. total
Coking Plant	10/1984	3 years	150M€	10/1987	5 years	n/a	+475Kt	475Kt	790Kt
Upgrade 1	1990	2 years	110M€	1992	12 years	n/a	+475Kt	940Kt	790Kt
Total			260M€		17 years				

If the forecasting shows a certainty in product price and requirement growth (i.e. DRI, crude steel, by-products) over the time (i.e. positive increasing trend line) that are sufficient for generating profit, the action upon expansion is likely to be carried out. Still, the decision is made under uncertain market behavior and technological advances. Another option is to employ DCFA analysis and applicable for the processing industry ROV methods together to confirm results.

[3]The original costs are in FIM. FIM/Eur= 5.94573 was applied as of 28/02/2002

Appendix B GasMat project description

Gas to Material (GasMat) is a three-year research project in cooperation with SINTEF Technology and Society, NTNU, and GasMat Consortium announced in 2008. The latter is represented by the companies StatoilHydro ASA, Celsa Armeringsstål AS, Sydvaranger Gruve AS, LKAB and Höganäs AB. The overall project is about possible advantages and disadvantages of running DRI iron and steel production cluster in Norway.

An initial coordinated design has been suggested by Midthun et al. (2008) for further economic modeling and analysis. It can be described as natural gas fired integrated steel cluster and includes several plant units to be run jointly. They are Air Separation unit (ASU) plant, Natural gas separation (Separator) plant, Partial Oxidation (POX) plant, Combined Cycle gas fired turbine power (Power) plant, Direct Reduced Iron (DRI) plant, and Steel production plant.

An extended version of a cluster design includes Carbon Black production plant and Methanol production plant in order to increase utilization rate of excessive product outputs arising at Separator plant and POX plant correspondingly. An overall network flow of raw material (inputs), products (outputs) and intermediate products (by-products) within the proposed design of GasMat cluster is presented in the Figure 17

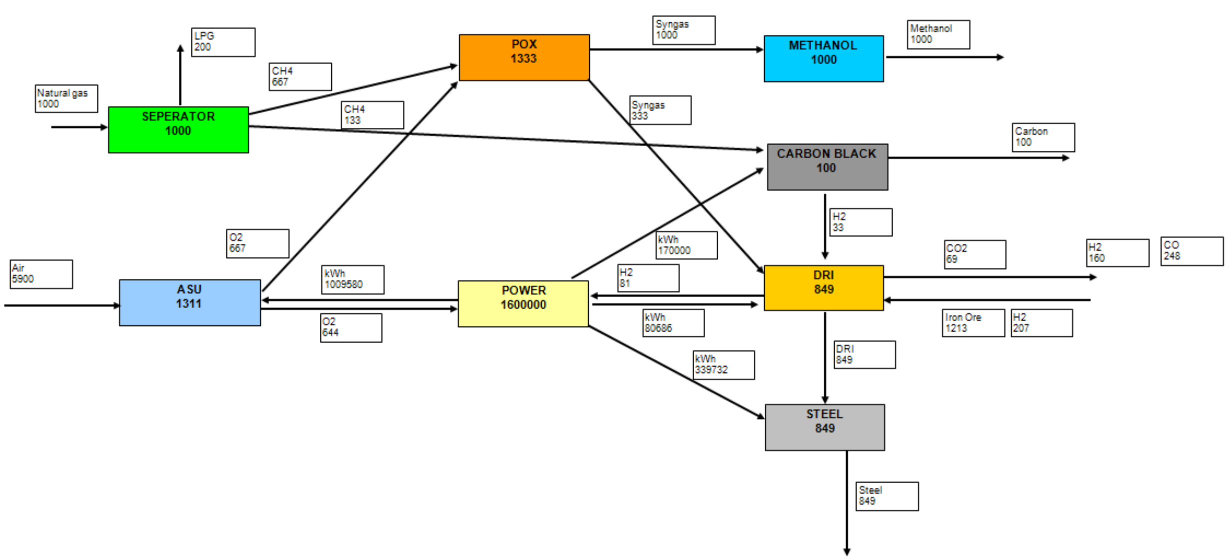


Figure 17: Possible design of GasMat industrial cluster

The term cluster is often used for a concentration of companies, organization and service providers in region with interconnected value chains, but not necessarily located in the same location. The intended location of this cluster is close to the industrial facility at Tjeldbergodden, south of Trondheim, offering good links to existing infrastructure such as an incoming natural gas pipeline, methanol plant and harbor already available. The term integrated steel cluster should be then interpreted as synonym of integrated steel park. A brief technical economic description of each plant is presented below.

Air separation plant

Air separation plant take atmospheric air and through processes of purification, cleaning, compression, cooling, liquefaction and distillation, breaks the air into its primary constituents and commodity chemicals nitrogen, argon and oxygen, which is necessary for steel production. Small quantities of neon, helium, krypton, and xenon are present at constant concentrations and can be separated as products.

Three different technologies are used for the separation of air: cryogenic distillation, ambient temperature adsorption, and membrane separations. Membrane technology is economical for the production of nitrogen and oxygen-enriched air (up to about 40% oxygen) at small scale. Adsorption technology produces nitrogen and medium-purity oxygen (90% oxygen) at flow rates up to 100 tons per day. The cryogenic process can generate oxygen or nitrogen at flows of 2500 tons per day from a single plant and make the full range of products. Within the industrial steel park, an ASU plant operates as supplier of oxygen for steel and electricity production processes. ASU has strong interconnections with partial oxidation plant (POX), integrated gas fired combine cycle power plant, and CO_2 capturing unit.

Natural gas processing plant

Natural gas processing plant basically separates various hydrocarbons (i.e. methane, butane, propane, etc.) from the raw natural gas to produce so-called pipe line ready dry natural gas. It is also called liquefied petroleum gas (LPG), which consists mainly of pure methane. Both air and natural gas separation plants are strongly interconnected in the industrial steel cluster. They are the main suppliers of oxygen and methane in the steel making process. Within the cluster a natural gas separation plant is the primary source of methane for partial oxidation plant and a carbon black production plant.

Very often gas processing plant has to convert raw natural gas at a certain minimal production rate, otherwise it has to burn excessively accumulated gas in the high pressured sea pipe line due to technological and safety reasons. Within GasMat industrial steel park, excessively extracted natural gas can be converted into liquefied petroleum gas (LPG) and be sold in the market. While natural gas liquids (NGLs) such as the ethane, propane, butane, and pentanes must be removed from raw natural gas to form LPG, this does not mean that they are all 'waste products'. They are often sold as valuable by-products too.

Natural gas fired power plant and CO_2 capturing unit

GasMat Industrial Steel Park will consume large amounts of electricity. The combined cycle gas fired turbine power plant will produce electricity by using natural gas as combustion fuel. Since all the other facilities in the industrial park require electricity in their production, the power plant provides important links within the industrial steel park. Due to the characteristics of a gas power plant it is possible to change the electricity production quite rapidly. This is a useful property to be able to meet peak or low demands in the cluster and in the market.

Partial Oxidation plant

Partial oxidation plant is a major source of synthesis gas (syngas) for direct reduced iron plant. Another name of syngas is a reducing gas. Syngas consists primarily of hydrogen H_2, carbon monoxide CO, and very often some carbon dioxide CO_2, which acts as reducing agent. The syngas is produced from carbons, but it has less than half the energy density of natural gas. The DRI plant is a key plant in steel production. Methane and oxygen supplied by ASU and Separator plant correspondingly are converted into syngas at POX plant. After that, the syngas is forwarded to direct reduced iron plant and optionally to methanol plant.

Methanol production plant

As an option, GasMat industrial park may include methanol plant in case of excessive production of syngas at POX plant or favorable market opportunities. Methanol is used as a fuel and antifreeze in other industries and can create additional value for the cluster too. The syngas produced in large waste-to-energy gasification facilities can be used to generate electricity.

Carbon black production plant

One of the main reasons to introduce Carbon and Methanol plants within the existing cluster design is the technological process at a Separator plant, its minimal and maximal production capacity, as well as market environment with respect to demand and prices for LPG, carbon, methanol and steel. An excessive volume of extracted methane can be directly consumed by POX plant (steel production) and Carbon black plant (carbon production). Indirectly, methane converted into syngas at POX plant may be consumed by Methanol plant (production of methanol). In the case of unfavorable business environment, all methane produced at Separator plant may be converted into LPG and sold in the market. There is also a connection between carbon plant and direct reduced iron plant.

Direct reduced iron plant

Direct-reduced iron (DRI), which is also known as a sponge iron, is produced from direct reduction of iron ore (in form of lumps, pellets or fines) by a reducing gas produced from natural gas or coal. This process of directly reducing the iron ore in solid form by reducing gases is called direct reduction. The DRI plant interacts with the steel plant, the gas power plant and the partial pox plant in the cluster (in the proposed design of initial cluster). The connection to these plants is very close. In the literature there are many examples of integrated plants that include both a DRI plant and a steel plant run jointly.

Outputs from the DRI process include iron pellets or bricks, heat and gases. The iron and heat can be used directly in the steel plant, while the various gases (as well as heat) can be utilized by the gas fired power plant. In addition, the DRI plant can utilize heat and gases from the gas power plant and sell reduced iron directly to the market. If a carbon black plant is included in the cluster, the hydrogen (H_2) from the carbon black plant can be utilized by the DRI plant. The yearly production of DRI is expected at a rate of 1.6 million tons per year, which should require some 2.2 million tons of iron ore pellets raw material, a product LKAB specializes in.

Steel production plant

In Electric Arc Furnace (EAF), steel can be made from 100 per cent scrap metal feedstock. The quality of the steel resulting from scrap metal feedstock is hard to control, since it depends on the quality of the input material. In addition to scrap steel, EAF can also use metal from a blast furnace or DRI. The primary benefit of the EAF is a large reduction in specific energy (energy per unit weight) required to produce the steel. Another benefit is the flexibility: while blast furnaces cannot vary their production to a large degree, EAFs can rapidly start and stop. This flexibility allows the steel mill to vary its production according to demand (or supply of input materials). In the last stage of the production, steel mills turn molten steel into blooms, ingots, slabs and sheet through casting, hot rolling and cold rolling.

The inputs to the steel plant are iron scrap, iron pellets, electricity and oxygen. The iron pellets comes from the DRI plant and are used to improve the quality of the produced steel. The steel plant interacts very closely with DRI plant and is also linked to the gas power plant. From the DRI plant, iron pellets are input to the steel production. The heat from the steel plant can be used by the gas power plant, while the gas power plant can deliver electricity to the steel plant.

The integrated steel cluster will become an extension to an existing Norwegian natural gas value chain due to importance of natural gas for the cluster in general, and dominant role of gas processing plant in particular (Separator plant). The benefits of using LKAB's energy efficient iron ore pellets, Höganäs' consumption and sale of metal products, and StatoilHydro's skills in energy generation, gas refining and CO_2 reinjection back into the reservoirs in the North Sea may result in one of the world's efficient and environmentally cleanest industrial steel sites. However, the economic performance and profitability of GasMat cluster directly depends on affordability of gas prices for production of steel and by-products in the long term.

Appendix C GasMat Operational Model

It was very kind of SINTEF, Department of Applied Economics and Operations Research to provide us with a working version of GasMat network flow computer model for operation simulations. The given source code of WGMO Operational model was written in Mosel environment (i.e. Xpress-Mosel Version 2.4.0) and solved by Xpress solver engine (i.e. Xpress Optimizer Version 19.0).

Description of the model

The economic model behind the GasMat operational tool considers simplified input-output flows between plants and the market within the GasMat cluster. It simulates the physical flows of natural gas, iron ore, direct reduced iron, steel, carbon dioxide (CO_2), hydrogen (H_2), heat, power (kWh), etc... These flows of materials are modeled with respect to technological mass balance functions and coefficients, and thus are closer to reality. On top of that, the collected estimates of future cash flows are subject to cash flow analysis. The developed in this thesis DDCFA tool represents such a possibility.

Assumptions and limitations of Operational model

The GasMat Operational model reminds the Network Flow model with an extendable plant module design. In fact, the model is a combination of blending problem and maximum flow problem across the network. The current version of multiperiod GasMat Network Flow model posses all conventional components of network type except for the built-in inventories. Lack of inventory constraints doubts the necessity of incorporated time periods. Without inventories there is no direct connection between time periods. One of the reasons to drop inventory constraints is the historical growing trend in DRI, Steel and production of minor by-products despite the seasonality in demands and periodical market recession. Another reason is an assumption that demands are given. Moreover, everything what is produced will be sold on the market (e.g.domestic/international) at a market price.

The model is being developed for meeting the given demand in multiple periods ahead, but it currently acts as a single period deterministic model. Meeting the market requirements also requires valuation of economically appropriate productive capacities. The model simply assumes maximal capacity parameter and technologically reasoned minimal production requirements at Plants. So far, the given version of GasMat model is of deterministic type. It performs rather in a static than in dynamic way.

Investment or setup costs are assumed to occur only during the first/base period, while costs of investment links between existing plants remain over time periods. Input costs of raw materials, operation or production costs are dependent on installed capacities of plants in the Steel Park. By default, the parameters of GasMat Plants productive capacities are fixed over entire planning horizon. Operational costs are modeled to remain unchanged.

The model focuses on dynamic pricing over the time horizon, since it is the main growth factor of operating expenses and revenue metrics.

The procedures for dynamic capacity planning throughout the economic life span have not been modeled yet by SINTEF. In practice, a surplus or deficit of plant's productive capacities arise over the time in regard to business environment (i.e. market requirements for DRI and range of steel products). The conducted literature research in Subsection 3.2.2 reveales the developed approach of optimization capacity investments in the steel industry. Despite the lack of capacity planning and corresponding investments within GasMat operation model, hypothetic cash flows of such investment upgrades are employed in the developed DDCFA tool.

Transportation costs within GasMat Park are almost neglected in comparison to traditional network flow and distribution model. The explanation is hidden in original definition of terms cluster and park. All facilities are assumed to be located next to each other forming an Integrated Steel Park, but not a cluster with geographically spread facilities. Still, the operational model incorporates the fixed investment cost parameter for setting up links between installed plants for commodities flows.

SINTEF project team is still developing and improving the combined GasMat Production/Network flow model. In this thesis the early version of GasMat operation tool is used for generating necessary cash flows to be further analyzed in DDCFA tool. It is a part of suggested composite investment valuation approach. In compliance with SINTEF copyright, the code of operational model is depicted for demonstration purpose only. Adherent points of DDCFA model with Network Flow model are highlighted. Several integration adjustments have been added by the author of this thesis.

Source code listing of WGMO_GenFlow_Inv_v4_3.mos

```
model 'WGMO_Operational'
uses 'mmxprs','mmodbc','mmsystem';

!Comments model version
!New formulation of the flow variables (general wrt commodity).
!KM 06.10.2008
!Also a general price parameter (distinction of prices in/out of market?)
!Added result report for income and costs.
!KM 25.11.2008

! **************************
! * Setting some parameters *
! **************************
  writeln("Setting some default parameters");
  setparam("xprs_verbose",true); ! optimize with a lot of output
  setparam("xprs_loadnames",true);
  ! load names into optimizer - output with meaningful names
  setparam("xprs_maxiis",1); ! max 1 set of iis during getiis
  setparam("SQLdebug",true); ! for debugging the SQL queries
  ! default length might be to short - 8 characters
  setparam("SQLcolsize",255);
  ! string size for transfer between Mosel and ODBC
! ********************************
! * END -  Setting some parameters *
! ********************************

forward procedure writeResultsProfits
forward procedure writeResultsFlow
forward procedure writeResultsPlants
!Eugene_Maisiuk. Setting an Adherent Point between WGMO & DDCFA tools
forward procedure writePlantsCashFlows
!forward procedure writeClusterCashFlows
!End Eugene


!The sets in the model
declarations
  TIME:         set of integer  !The set of all time periods in the model
  PLANTS:       set of string !The set of all plants in the model
  COMMODITIES:  set of string !The set of all commodities in the model
```

```
end-declarations

!SQLconnect("DSN=Excel Files;DBQ=M:\\2007-2009 HiM_MSc_Logistics\\'09 Spring 4th Thesis\\THESIS Sintef-GassMat\\Code\\Xpress-MP\\Gassmat_Xpress_Inv_v2.xls")
!Excel XLSM files takes lower spce than XLS files due to internal compressing. However, it results in longer xpressmp model running time due to SQLconnect procedure
!SQLconnect("DSN=Excel Files;DBQ=M:\\2007-2009 HiM_MSc_Logistics\\'09 Spring 4th Thesis\\THESIS Sintef-GassMat\\Code\\Xpress-MP\\Gassmat_Xpress_Inv_v2.xlsm") !Excel 2007 is installed at HiM
SQLconnect('DSN=Excel Files;DBQ=C:\Documents and Settings\070346.STUD\Desktop\master\dev\trunk\Gassmat_Xpress_Inv_v2.xls')

SQLexecute("SELECT * FROM TimePeriods", TIME)
SQLexecute("SELECT * FROM PlantsInCluster", PLANTS)
SQLexecute("SELECT * FROM Commodities", COMMODITIES)

finalize(TIME)
finalize(PLANTS)
finalize(COMMODITIES)

!Parameters used in the cluster model
declarations
  !The prices of the commodities in the model
    PURCH_PRICE:     dynamic array(COMMODITIES,TIME) of real
    !Price paid for the commodities
    SALES_PRICE:     dynamic array(COMMODITIES,TIME) of real
    !Price obtained for the commodities
  !The seperator
    WET_GAS:         real ! fraction of the incoming gas that is wet gas
  !The ASU
    AIR_OXY:         real ! fraction of the incoming gas that is oxygen
  !The POX
  !The methanol plant
  !The DRI plant
    UTILIZATION_H2:    real ! percentage of h2 used in the dri production
    UTILIZATION_CO:    real ! percentage of co used in the dri productin
  !The steel plant
    DRI_MIX_STEEL:     real ! portion of dri in the steel production
  !The gas fired power plant
```

```
    EFFICIENCY_POWER: real ! power efficiency in the power plant

  !Network description - flow variables,description of links in the network
    LINKS:          dynamic array(PLANTS,PLANTS,COMMODITIES) of integer
    INV_COST_LINKS:    dynamic array(PLANTS,PLANTS,COMMODITIES) of integer

  !Capacity limitations in the plants, per unit investment cost,operation cost
    CAP_MAX:        array(PLANTS) of real
    CAP_MIN:        array(PLANTS) of real
    INV_UNIT_COST:     array(PLANTS) of real
    INV_FIXED_COST:    array(PLANTS) of real
    PROD_MIN:       array(PLANTS) of real
    COMM_INV:       array(PLANTS) of string
     !Commmodities which determine the investment costs in the plants
    OPER_UNIT_COST:    array(PLANTS) of real
    OPER_FIXED_COST:   array(PLANTS) of real
    COMM_OPER:         array(PLANTS) of string
     !Commmodities which determine the operational costs in the plants
end-declarations

!Reading data from Excel
!Data for the Seperator
  WET_GAS:= SQLreadreal('SELECT Wet_gas FROM Seperator_Data')
!Data for the ASU
  AIR_OXY:= SQLreadreal('SELECT Oxygen_air FROM ASU_Data')
!Data for the POX
!Data for the DRI
  UTILIZATION_H2:= SQLreadreal('SELECT Utilization_H2 FROM DRI_Data')
  UTILIZATION_CO:= SQLreadreal('SELECT Utilization_CO FROM DRI_Data')
!Data for the Power Plant
  EFFICIENCY_POWER:= SQLreadreal('SELECT Efficiency FROM PP_Data')
!Data for the Steel plant
  DRI_MIX_STEEL:= SQLreadreal('SELECT DRI_fraction FROM Steel_Data')
!Data for the Methanol plant

!Links in the cluster
  SQLexecute("SELECT From_plant, To_plant, Commodity, Link FROM
     Links_Cluster", LINKS)
  SQLexecute("SELECT From_plant, To_plant, Commodity, Inv_Cost FROM
     Links_Cluster", INV_COST_LINKS)
```

```

!Prices of the commodities in the cluster
  SQLexecute("SELECT Commodities, Time, Purch_price FROM Price_Data", PURCH_PRICE)
  SQLexecute("SELECT Commodities, Time, Sale_price FROM Price_Data", SALES_PRICE)

!Investment input (capacity and costs)
  SQLexecute("SELECT Plant, Max_Capacity FROM Investment", CAP_MAX)
  SQLexecute("SELECT Plant, Min_Capacity FROM Investment", CAP_MIN)
  SQLexecute("SELECT Plant, Cost_Par FROM Investment", INV_UNIT_COST)
  SQLexecute("SELECT Plant, Fixed_Cost FROM Investment", INV_FIXED_COST)
  SQLexecute("SELECT Plant, Min_Production FROM Investment", PROD_MIN)
  SQLexecute("SELECT Plant, Det_Comm FROM Investment", COMM_INV)

!Operation input (fixed and variable costs)
  SQLexecute("SELECT Plant, Cost_Par FROM Operation", OPER_UNIT_COST)
  SQLexecute("SELECT Plant, Fixed_Cost FROM Operation", OPER_FIXED_COST)
  SQLexecute("SELECT Plant, Det_Comm FROM Operation", COMM_OPER)

SQLdisconnect

bigM:=9999999999999999

!Decision variables used in the cluster model
declarations
  !Network variables
    capacity:    array(PLANTS) of mpvar
    !Installed capacity in the different plants
    flow:        dynamic array(PLANTS,PLANTS,COMMODITIES,TIME) of mpvar
    !Flow commodities between the plants (and the market)
    inv_plant:   dynamic array(PLANTS) of mpvar
    !binary variable to indicate whether or not the plant is installed
    inv_link:    dynamic array(PLANTS,PLANTS,COMMODITIES) of mpvar
    !binary variable for investment in infrastructure

  !The seperator
    gas_sep:     array(TIME) of mpvar  ! natural gas that enters the seperator
    ch4_sep:     array(TIME) of mpvar  ! dry gas from the seperator
    lpg_sep:     array(TIME) of mpvar  ! wet gas from the seperator
```

```
!The ASU
  air_asu:     array(TIME) of mpvar  ! air that enters the ASU
  o2_asu:      array(TIME) of mpvar  ! oxygen from the ASU
  n2_asu:      array(TIME) of mpvar  ! nitrogen from the ASU
  kwh_asu:     array(TIME) of mpvar  ! total usage of kwh in the ASU
!The POX
  ch4_pox:     array(TIME) of mpvar  ! methane that enters the pox
  o2_pox:      array(TIME) of mpvar  ! oxygen that enters the pox
  h2_pox:      array(TIME) of mpvar  ! hydrogen produced in the pox
  co_pox:      array(TIME) of mpvar  ! carbonmonoksid produced in the pox
  syngas_pox:    array(TIME) of mpvar  ! syngas produced in the pox
!The methanol plant
  ch3oh_met:     array(TIME) of mpvar  ! methanol produced in the plant
  h2_met:      array(TIME) of mpvar  ! hydrogen that enters the plant
  co_met:      array(TIME) of mpvar  ! carbonmonoksid that enters the plant
  syngas_met:    array(TIME) of mpvar  ! syngas that enters the plant
!The DRI plant
  fe_h2_dri:     array(TIME) of mpvar  ! dri produced in the plant by using h2
  fe_co_dri:     array(TIME) of mpvar  ! dri produced in the plant by using co
  ore_dri:     array(TIME) of mpvar  ! ore input to the dri plant
  ore_h2_dri:    array(TIME) of mpvar
  ! iron ore that enters the plant (pellets) used by h2
  ore_co_dri:    array(TIME) of mpvar
  ! iron ore that enters the plant (pellets) used by co
  h2_dri:      array(TIME) of mpvar  ! hydrogen that enters the plant
  co_dri:      array(TIME) of mpvar  ! carbonmonoksid that enters the plant
  syngas_dri:    array(TIME) of mpvar  ! syngas that enters the plant
  h20_dri:     array(TIME) of mpvar  ! h20 produced in the dri
  co2_dri:     array(TIME) of mpvar  ! co2 produced in the dri
  kwh_dri:     array(TIME) of mpvar  ! total usage of kwh in the dri plant
!The steel plant
  prod_steel:    array(TIME) of mpvar  ! steel production in the plant
  dri_steel:     array(TIME) of mpvar  ! dri used in the steel production
  scrap_steel:   array(TIME) of mpvar  ! scrap used in the steel production
  kwh_steel:     array(TIME) of mpvar  ! power used in the steel production
!The gas fired power plant
  prod_kwh:    array(TIME) of mpvar
  ! total production of kwh in the power plant (adjusted for efficiency)
  o2_power:    array(TIME) of mpvar  ! input of oxygen to the power plant
```

```
    co2_power:     array(TIME) of mpvar  ! output of co2 from the power plant
    kwh_power:     array(TIME) of mpvar  ! output of kwh from the power plant
    prod_ch4_kwh:  array(TIME) of mpvar  ! power production in the plant
    prod_h2_kwh:   array(TIME) of mpvar  ! power production in the plant
    prod_co_kwh:   array(TIME) of mpvar  ! power production in the plant
    ch4_power:     array(TIME) of mpvar  ! methane used in the power
        production
    h2_power:      array(TIME) of mpvar  ! hydrogen used in the power
        production
    co_power:    array(TIME) of mpvar  ! co used in the power production
    syngas_power: array(TIME) of mpvar  ! syngas used in the power
        production
    o2_ch4_power: array(TIME) of mpvar  ! o2 used in the power production
    o2_h2_power:  array(TIME) of mpvar  ! o2 used in the power production
    o2_co_power:  array(TIME) of mpvar  ! o2 used in the power production
    h20_ch4_power:  array(TIME) of mpvar  ! h20 produced in the power
        production
    h20_h2_power: array(TIME) of mpvar  ! h20 produced in the power
        production
    co2_ch4_power:  array(TIME) of mpvar  ! co2 produced in the power
        production
    co2_co_power: array(TIME) of mpvar  ! co2 produced in the power
        production
  !The carbon black plant
    prod_cb_c:     array(TIME) of mpvar
    ! total production of carbon in the carbon black plant
    kwh_cb:      array(TIME) of mpvar
    ! total usage of kwh in the carbon black plant
    ch4_cb:      array(TIME) of mpvar
    ! usage of methane in the carbon black plant
    prod_cb_h2:    array(TIME) of mpvar
    ! production of hydrogen in the carbon black plant
end-declarations

forall(i in PLANTS, j in PLANTS, c in COMMODITIES, t in TIME) do
  if LINKS(i,j,c)=1 then
    create(flow(i,j,c,t))
  end-if
end-do

forall(i in PLANTS, j in PLANTS, c in COMMODITIES) do
```

```
  if LINKS(i,j,c)=1 then
    create(inv_link(i,j,c))
    inv_link(i,j,c) is_binary
  end-if
end-do

forall(i in PLANTS-{'MARKET'}) do
  create(inv_plant(i))
  inv_plant(i) is_binary
end-do

!***************************************************************************
!********************************
!*** INVESTMENT COSTS**** ********
!********************************
!In this section, the formulation for the capacity investments are given
!as well as the associated costs

!Capacity investments
forall(p in PLANTS) do
  MAX_CAPACITY(p):= capacity(p) <= CAP_MAX(p)
  MIN_CAPACITY(p):= capacity(p) >= CAP_MIN(p)

  PLANT_INVESTMENT(p):= capacity(p) <= bigM * inv_plant(p)
end-do

forall(i in PLANTS, j in PLANTS, c in COMMODITIES, t in TIME) do
! LINK_INVESTMENT2(i,j,c):= flow(i,j,c,t) <= bigM * inv_plant(i)
! LINK_INVESTMENT3(i,j,c):= flow(i,j,c,t) <= bigM * inv_plant(j)
  LINK_INVESTMENT1(i,j,c):= flow(i,j,c,t) <= bigM * inv_link(i,j,c)
end-do

forall(p in PLANTS) do
  INVESTMENT_COST_PLANT(p):= inv_plant(p) * INV_FIXED_COST(p) + capacity(p)
      * INV_UNIT_COST(p)
end-do

INVESTMENT_COST:= sum(p in PLANTS) INVESTMENT_COST_PLANT(p) +
            sum(i in PLANTS, j in PLANTS, c in COMMODITIES) INV_COST_LINKS(i,j
                ,c) * inv_link(i,j,c)

```

```
!*************************************
!*** END - INVESTMENT COSTS**** ********
!*************************************


!************************************************************************
!*******************************
!*** OPERATION COSTS**** ********
!*******************************
!In this section, the formulation of the operational costs are given

forall(p in PLANTS) do
  forall (t in TIME)do
    OPERATION_COST_PLANT(p,t):=sum(i in PLANTS, c in COMMODITIES | c =
        COMM_OPER(p)) (flow(i,p,c,t) + flow(p,i,c,t)) * OPER_UNIT_COST(p)
  end-do
end-do

OPERATION_COST:= sum(p in PLANTS, t in TIME) ( inv_plant(p) *
    OPER_FIXED_COST(p) ) + sum(p in PLANTS, t in TIME) OPERATION_COST_PLANT(p
    ,t)

!*************************************
!*** END - OPERATION COSTS**** ********
!*************************************


!Eugene_Maisiuk. Setting an Adherent Point between WGMO & DDCFA tools
!************************************************************************
!*******************************
!*** INPUT TO THE PLANT  *********
!*******************************
!Description: External input for a plant

forall (p in PLANTS) do
  forall(t in TIME) do
    COST_INPUT_PLANT(p,t):= sum(c in COMMODITIES) PURCH_PRICE(c,t) * sum(i
        in PLANTS) flow(i,p,c,t)
  end-do
end-do
!*************************************
```

```
!*** END - INPUT TO THE CLUSTER ********
!**************************************
!EndEugene


!************************************************************************
!********************************
!*** INPUT TO THE CLUSTER ********
!********************************
!Description: External input to the cluster. Also connection to the different parts in the cluster is given:
  !The resource is on the left hand side in the constraints, while the right hand side
  !gives the usage in the different plants

COST_OF_INPUT:= sum(c in COMMODITIES, t in TIME) PURCH_PRICE(c,t) * sum(p in PLANTS) flow('MARKET',p,c,t)

forall(t in TIME) do
  COST_INPUT_PERIOD(t):= sum(c in COMMODITIES) PURCH_PRICE(c,t) * sum(p in PLANTS) flow('MARKET',p,c,t)
end-do
!**************************************
!*** END - INPUT TO THE CLUSTER ********
!**************************************

!************************************************************************
!*********************
!*** SEPERATOR ********
!*********************
!Description: Seperates dry and wet gas from the incoming natural gas
    !The left hand side gives the incoming resource, and the right hand side the usage in the plant

!Input balance
forall(t in TIME) do
  IB_SEP(t):= sum(p in PLANTS) flow(p,'SEPERATOR','Natural gas',t) = gas_sep(t)
end-do

!Mass balance
```

```
forall(t in TIME) do
  MB_SEP1(t):= lpg_sep(t) = WET_GAS * gas_sep(t)
  MB_SEP2(t):= ch4_sep(t) = (1 - WET_GAS) * gas_sep(t)
end-do

!Production limits
forall(t in TIME) do
  PROD_SEP_CONSTR1(t):= gas_sep(t) <= capacity('SEPERATOR')
  PROD_SEP_CONSTR2(t):= gas_sep(t) >= PROD_MIN('SEPERATOR')
end-do

!Output balance
forall(t in TIME) do
  OB_SEP1(t):= lpg_sep(t) = sum(i in PLANTS) flow('SEPERATOR',i,'LPG',t)
  OB_SEP2(t):= ch4_sep(t) = sum(i in PLANTS) flow('SEPERATOR',i,'CH4',t)
end-do
!***************************
!***   END - SEPERATOR    ***
!***************************

!************************************************************************
!*********************
!***   ASU         ***
!*********************
!Description: Seperate the oxygen from the air

!Input balance
forall(t in TIME) do
  IB_ASU1(t):= air_asu(t) = sum(p in PLANTS) flow(p,'ASU','Air',t)
  IB_ASU2(t):= kwh_asu(t) = sum(p in PLANTS) flow(p,'ASU','kWh',t)
end-do

!Mass balance
forall(t in TIME) do
  MB_ASU1(t):= (1/32) * o2_asu(t) = (1/144) * air_asu(t)
  MB_ASU2(t):= (1/112) * n2_asu(t) = (1/144) * air_asu(t)
  MB_ASU3(t):= o2_asu(t) = (1/770) * kwh_asu(t)     !assumes 770 kwh per tonn o2

end-do

```

```
!Production limits
forall(t in TIME) do
  PROD_ASU_CONSTR1(t):= o2_asu(t) <= capacity('ASU')
  PROD_ASU_CONSTR2(t):= o2_asu(t) >= PROD_MIN('ASU')
end-do

!Output balance
forall(t in TIME) do
  OB_ASU1(t):= o2_asu(t) = sum(i in PLANTS) flow('ASU',i,'O2',t)
end-do
!***************************
!***    END - ASU         ***
!***************************

!*************************************************************************
!*********************
!***    POX        ***
!*********************
!Description: Creates syntheses gas from methane

!Input balance
forall(t in TIME) do
  IB_POX1(t):= ch4_pox(t) = sum(i in PLANTS) flow(i,'POX','CH4',t)
  IB_POX2(t):= o2_pox(t) = sum(i in PLANTS) flow(i,'POX','O2',t)
end-do

!Mass balance
forall(t in TIME) do
  MB_POX1(t):= (1/8) * h2_pox(t) = (1/32) * ch4_pox(t)
  MB_POX2(t):= (1/8) * h2_pox(t) = (1/32) * o2_pox(t)
  MB_POX3(t):= (1/56) * co_pox(t) = (1/32) * ch4_pox(t)
  MB_POX4(t):= (1/56) * co_pox(t) = (1/32) * o2_pox(t)
  MB_POX5(t):= syngas_pox(t) = h2_pox(t) + co_pox(t)
end-do

!Production limits
forall(t in TIME) do
  PROD_POX_CONSTR1(t):= h2_pox(t)+ co_pox(t)<= capacity('POX')
  PROD_POX_CONSTR2(t):= h2_pox(t)+ co_pox(t)>= PROD_MIN('POX')
end-do

```

```
!Output balance
forall(t in TIME) do
  !OB_POX1(t):= h2_pox(t) = sum(i in PLANTS) flow('POX',i,'H2',t)
  !OB_POX2(t):= co_pox(t) = sum(i in PLANTS) flow('POX',i,'CO',t)
 OB_POX1(t):= syngas_pox(t) = sum(i in PLANTS) flow('POX',i,'Syngas',t)
end-do
!***************************
!***    END - POX          ***
!***************************

!*************************************************************************
!*********************
!***    METHANOL      ***
!*********************
!Description: produces methanol from syntheses gas

!Input balance
forall(t in TIME) do
  !IB_MET1(t):= h2_met(t) = sum(i in PLANTS) flow(i,'METHANOL','H2',t)
  !IB_MET2(t):= co_met(t) = sum(i in PLANTS) flow(i,'METHANOL','CO',t)
 IB_MET1(t):= syngas_met(t) = sum(i in PLANTS) flow(i,'METHANOL','Syngas',t)
 IB_MET2(t):= h2_met(t) = (1/8) * syngas_met(t) + sum(i in PLANTS) flow(i,'METHANOL','H2',t)
 IB_MET3(t):= co_met(t) = (7/8) * syngas_met(t) + sum(i in PLANTS) flow(i,'METHANOL','CO',t)
end-do

!Mass balance
forall(t in TIME) do
 MB_MET1(t):= (1/32) * ch3oh_met(t) = (1/4) * h2_met(t)
 MB_MET2(t):= (1/32) * ch3oh_met(t) = (1/28) * co_met(t)
end-do

!Production limits
forall(t in TIME) do
 PROD_MET_CONSTR1(t):= ch3oh_met(t) <= capacity('METHANOL')
 PROD_MET_CONSTR2(t):= ch3oh_met(t) >= PROD_MIN('METHANOL')
end-do

!Output balance
```

```
forall(t in TIME) do
  OB_MET(t):= ch3oh_met(t) = sum(i in PLANTS) flow('METHANOL',i,'Methanol',t)
end-do
!***************************
!***    END - METHANOL      ***
!***************************

!*************************************************************************
!*********************
!***    DRI PLANT    ***
!*********************
!Description: The DRI plant produces DRI from iron ore (pellets) by using reducing gas

!Input balance
forall(t in TIME) do
  !IB_DRI1(t):= h2_dri(t) = sum(i in PLANTS) flow(i,'DRI','H2',t)
  !IB_DRI2(t):= co_dri(t) = sum(i in PLANTS) flow(i,'DRI','CO',t)
  IB_DRI3(t):= ore_dri(t) = sum(i in PLANTS) flow(i,'DRI','Iron Ore',t) ! Input from an external market
  IB_DRI4(t):= ore_dri(t) = ore_h2_dri(t) + ore_co_dri(t)        !Balance between ore used by H2 and CO
  IB_DRI5(t):= syngas_dri(t) = sum(i in PLANTS) flow(i,'DRI','Syngas',t)
  IB_DRI6(t):= h2_dri(t) = (1/8) * syngas_dri(t) + sum(i in PLANTS) flow(i,'DRI','H2',t)
  IB_DRI7(t):= co_dri(t) = (7/8) * syngas_dri(t) + sum(i in PLANTS) flow(i,'DRI','CO',t)
  IB_DRI8(t):= kwh_dri(t) = sum(i in PLANTS) flow(i,'DRI','kWh',t)
end-do

!Mass balance
forall(t in TIME) do
  MB_DRI1(t):= (1/112) * fe_h2_dri(t) = (1/160) * ore_h2_dri(t)
  MB_DRI2(t):= (1/112) * fe_h2_dri(t) = (1/6) * h2_dri(t) * UTILIZATION_H2
  MB_DRI3(t):= (1/112) * fe_h2_dri(t) = (1/54) * h20_dri(t)

  MB_DRI4(t):= (1/112) * fe_co_dri(t) = (1/160) * ore_co_dri(t)
  MB_DRI5(t):= (1/112) * fe_co_dri(t) = (1/84) * co_dri(t) * UTILIZATION_CO
  MB_DRI6(t):= (1/112) * fe_co_dri(t) = (1/132) * co2_dri(t)

```

```
  MB_DRI7(t):= fe_h2_dri(t) + fe_co_dri(t) = (1/95) * kwh_dri(t)        ! assumes 95 kwh per tonn dri
end-do

!Production limits
forall(t in TIME) do
  FE_DRI_CONSTR1(t):= fe_h2_dri(t) + fe_co_dri(t) <= capacity('DRI')
  FE_DRI_CONSTR2(t):= fe_h2_dri(t) + fe_co_dri(t) >= PROD_MIN('DRI')
end-do

!Output balance
forall(t in TIME) do
  OB_DRI1(t):= fe_h2_dri(t) + fe_co_dri(t) = sum(j in PLANTS) flow('DRI',j,'DRI',t)
  OB_DRI2(t):= (1-UTILIZATION_H2) * h2_dri(t) = sum(j in PLANTS) flow('DRI',j,'H2',t)
  OB_DRI3(t):= (1-UTILIZATION_CO) * co_dri(t) = sum(j in PLANTS) flow('DRI',j,'CO',t)
  OB_DRI4(t):= co2_dri(t) = sum(j in PLANTS) flow('DRI',j,'CO2',t)
end-do
!***************************
!***    END - DRI PLANT    ***
!***************************

!**********************
!***    STEEL PLANT    ***
!**********************
!Description: use the DRI to produce steel
  !steel scrap comes from an external market
  !steel is sent to a market place

!Input balance
forall(t in TIME) do
  IB_STEEL1(t):= kwh_steel(t) = sum(i in PLANTS) flow(i,'STEEL','kWh',t)
  IB_STEEL2(t):= scrap_steel(t) = sum(i in PLANTS) flow(i,'STEEL','Steel scrap',t)
  IB_STEEL3(t):= dri_steel(t) = sum(i in PLANTS) flow(i,'STEEL','DRI',t)
end-do

!Mass balance
forall(t in TIME) do
```

```
  MB_STEEL1(t):= prod_steel(t) = (1/400) * kwh_steel(t)     !assumes 400 kwh per tonn steel
  MB_STEEL2(t):= prod_steel(t) = dri_steel(t) + scrap_steel(t)
end-do

!Production limits
forall(t in TIME) do
  PROD_STEEL_CONSTR1(t):= prod_steel(t) <= capacity('STEEL')
  PROD_STEEL_CONSTR2(t):= prod_steel(t) >= PROD_MIN('STEEL')
end-do

!DRI content
  !fraction of input that should be dri: DRI_MIX_STEEL = dri / (dri + scrap)
forall(t in TIME) do
  DR_STEEL(t):= dri_steel(t) = DRI_MIX_STEEL * (dri_steel(t) + scrap_steel(t))
end-do

!Output balance
forall(t in TIME) do
  OB_STEEL(t):= prod_steel(t) = sum(j in PLANTS) flow('STEEL',j,'Steel',t)
end-do
!****************************
!***   END - STEEL PLANT   ***
!****************************

!prod_steel(1) = (1/400) * kwh_steel(1)

!********************************
!***   GAS FIRED POWER PLANT   ***
!********************************
!Description: produce power from natural gas (methane, hydrogen and co)

!Input balance
forall(t in TIME) do
  IB_PP1(t):= o2_ch4_power(t) + o2_h2_power(t) + o2_co_power(t) = sum(i in PLANTS) flow(i,'POWER','O2',t)
  IB_PP2(t):= ch4_power(t) = sum(i in PLANTS) flow(i,'POWER','CH4',t)
  !IB_PP3(t):= h2_power(t) = sum(i in PLANTS) flow(i,'POWER','H2',t)
  !IB_PP4(t):= co_power(t) = sum(i in PLANTS) flow(i,'POWER','CO',t)
  IB_PP3(t):= syngas_power(t) = sum(i in PLANTS) flow(i,'POWER','Syngas',t)
```

```
  IB_PP4(t):= h2_power(t) = (1/8) * syngas_power(t) + sum(i in PLANTS) flow(
      i,'POWER','H2',t)
  IB_PP5(t):= co_power(t) = (7/8) * syngas_power(t) + sum(i in PLANTS) flow(
      i,'POWER','CO',t)
end-do

!Mass balance
forall(t in TIME) do
  MB_POWER_CH4_1(t):= (1/0.24448) * prod_ch4_kwh(t) = (1/16) * ch4_power(t)
      * 1000000
  MB_POWER_CH4_2(t):= (1/0.24448) * prod_ch4_kwh(t) = (1/64) * o2_ch4_power(
      t) * 1000000
  MB_POWER_CH4_3(t):= (1/44) * co2_ch4_power(t) = (1/16) * ch4_power(t)
  MB_POWER_CH4_4(t):= (1/36) * h20_ch4_power(t) = (1/16) * ch4_power(t)

  MB_POWER_H2_1(t):= (1/0.158888) * prod_h2_kwh(t) = (1/4) * h2_power(t) *
      1000000
  MB_POWER_H2_2(t):= (1/0.158888) * prod_h2_kwh(t) = (1/32) * o2_h2_power(t)
       * 1000000
  MB_POWER_H2_3(t):= (1/36) * h20_h2_power(t) = (1/4) * h2_power(t)

  MB_POWER_CO_1(t):= (1/0.1555688) * prod_co_kwh(t) = (1/56) * co_power(t) *
       1000000
  MB_POWER_CO_2(t):= (1/0.1555688) * prod_co_kwh(t) = (1/32) * o2_co_power(t
      ) * 1000000
  MB_POWER_CO_3(t):= (1/88) * co2_co_power(t) = (1/56) * co_power(t)
end-do

!Energy efficiency and total production
forall(t in TIME) do
  EE_PP(t):= prod_kwh(t) = EFFICIENCY_POWER * (prod_ch4_kwh(t) + prod_h2_kwh
      (t) + prod_co_kwh(t))
end-do

!Production limits
forall(t in TIME) do
  PROD_POWER_CONSTR1(t):= prod_kwh(t) <= capacity('POWER')
  PROD_POWER_CONSTR2(t):= prod_kwh(t) >= PROD_MIN('POWER')
end-do

!Output balance
```

```
forall(t in TIME) do
  OB_PP1(t):= prod_kwh(t) = sum(j in PLANTS) flow('POWER',j,'kWh',t)
  OB_PP2(t):= co2_ch4_power(t) + co2_co_power(t) = sum(j in PLANTS) flow('
      POWER',j,'CO2',t)
end-do
!*************************************
!***    END - GAS FIRED POWER PLANT    ***
!*************************************

!********************************
!***    CARBON BLACK              ***
!********************************
!Description: produce carbon (and hydrogen) from methane

!Input balance
forall(t in TIME) do
  IB_CB1(t):= ch4_cb(t) = sum(i in PLANTS) flow(i,'CARBON BLACK','CH4',t)
  IB_CB2(t):= kwh_cb(t) = sum(i in PLANTS) flow(i,'CARBON BLACK','kWh',t)
end-do

!Mass balance
forall(t in TIME) do
  MB_CB1(t):= prod_cb_c(t) = (12/16) * ch4_cb(t)
  MB_CB2(t):= prod_cb_h2(t) = (4/16) * ch4_cb(t)
  MB_CB3(t):= prod_cb_c(t) = (1/1700) * kwh_cb(t)      !assumes 1700 kwh per
      tonn carbon black

end-do

!Production limits
forall(t in TIME) do
  PROD_CB_CONSTR1(t):= prod_cb_c(t) <= capacity('CARBON BLACK')
  PROD_CB_CONSTR2(t):= prod_cb_c(t) >= PROD_MIN('CARBON BLACK')
end-do

!Output balance
forall(t in TIME) do
  OB_CB1(t):= prod_cb_c(t) = sum(j in PLANTS) flow('CARBON BLACK',j,'Carbon
      ',t)
  OB_CB2(t):= prod_cb_h2(t) = sum(j in PLANTS) flow('CARBON BLACK',j,'H2',t)
end-do
```

```
!**************************************
!***    END - CARBON BLACK            ***
!**************************************

!Eugene_Maisiuk. Setting an Adherent Point between WGMO & DDCFA tools
!********************************
!*** OUTPUT FROM THE PLANTS   *****
!********************************
!Description: Output from the plants shows profitability/performing at loss in the cluster
!QUESTION: Are OPERATION_COST_PLANT (p,t) and REVENUE_FROM_PLANT(p,t) defined correctly?

forall (p in PLANTS) do
  forall (t in TIME) do
    !It is defined above in OPERATION COSTS section
    !OPERATION_COST_PLANT(p,t):=sum(i in PLANTS, c in COMMODITIES | c = COMM_OPER(p)) (flow(i,p,c,t) + flow(p,i,c,t)) * OPER_UNIT_COST(p)

    REVENUE_FROM_PLANT(p,t):= sum(i in PLANTS, c in COMMODITIES ) flow(p,i,c,t)*SALES_PRICE(c,t)

    if t=1 then
      PROFIT_FROM_PLANT(p,t):=REVENUE_FROM_PLANT(p,t) - COST_INPUT_PLANT(p,t) - OPERATION_COST_PLANT(p,t)-INVESTMENT_COST_PLANT(p)
     else
      PROFIT_FROM_PLANT(p,t):=REVENUE_FROM_PLANT(p,t)-OPERATION_COST_PLANT(p,t)
    end-if
  end-do
end-do
!EndEugene

!************************************************************************
!********************************
!*** OUTPUT FROM THE CLUSTER *****
!********************************
!Description: Output from the cluster that can go to different markets
  !The product is on the left hand side in the constraints, while the right hand side
  !gives the production in the different plants
```

```
REVENUE_FROM_OUTPUT:= sum(c in COMMODITIES, t in TIME) SALES_PRICE(c,t) * sum(p in PLANTS) flow(p,'MARKET',c,t)

forall(t in TIME) do
  REVENUE_PERIOD(t):= sum(c in COMMODITIES) SALES_PRICE(c,t) * sum(p in PLANTS) flow(p,'MARKET',c,t)
end-do
!*************************************
!*** END - INPUT TO THE CLUSTER ********
!*************************************

GOAL:= REVENUE_FROM_OUTPUT - COST_OF_INPUT - INVESTMENT_COST - OPERATION_COST

maximize(GOAL)
writeln(getsol(GOAL))
writeln(getsol(REVENUE_FROM_OUTPUT))
writeln(getsol(COST_OF_INPUT))
writeln(getsol(INVESTMENT_COST))
writeln(getsol(OPERATION_COST))

writeResultsProfits
writeResultsFlow
writeResultsPlants
!Eugene_Maisiuk Setting an Adherent Point between WGMO & DDCFA tools
writePlantsCashFlows
!EndEugene

procedure writeResultsProfits
  declarations
    investment_s: array(PLANTS) of string
    cost_s:       dynamic array(COMMODITIES) of string
    income_s:     dynamic array(COMMODITIES) of string
    profit_s:     string

    statistics_s: array(PLANTS, TIME, 1..3) of string
  end-declarations

forall(p in PLANTS) do
  investment_s(p) += ";" + p + ";" +
```

```
    string(getsol(inv_plant(p)) * INV_FIXED_COST(p) + getsol(capacity(p)) * INV_UNIT_COST(p)) + ";" + " "
end-do

forall(c in COMMODITIES) do
  test_link(c):= sum(i in PLANTS, t in TIME | LINKS('MARKET',i,c) = 1) getsol(flow('MARKET',i,c,t))
end-do

forall(c in COMMODITIES | test_link(c) > 0) do
  forall(t in TIME) do
    cost_s(c) += string(PURCH_PRICE(c,t) * sum(p in PLANTS) getsol(flow('MARKET',p,c,t))) + ";"
  end-do
end-do

forall(c in COMMODITIES) do
  test_link2(c):= sum(i in PLANTS, t in TIME | LINKS(i,'MARKET',c) = 1) getsol(flow(i,'MARKET',c,t))
end-do

forall(c in COMMODITIES | test_link2(c) > 0) do
  forall(t in TIME) do
    income_s(c) += string(SALES_PRICE(c,t) * sum(p in PLANTS) getsol(flow(p,'MARKET',c,t))) + ";"
  end-do
end-do

forall(t in TIME) do
  if t = 1 then
    profit_s += "Profit" + ";" + ";" + string(getsol(REVENUE_PERIOD(t)) - getsol(COST_INPUT_PERIOD(t)) - getsol(INVESTMENT_COST))
  else
    profit_s += ";" + string(getsol(REVENUE_PERIOD(t)) - getsol(COST_INPUT_PERIOD(t)))
  end-if
end-do

count:=1
count2:=1
count3:=1
```

```
fopen("WGMO_Profits.sol",F_OUTPUT)
  writeln(";" + ";" + "Time period")
  writeln(";" + ";" + "1" + ";" + "2")
  forall(p in PLANTS) do
    if count=1 then
      writeln("Investments" + investment_s(p))
    else
      writeln(investment_s(p))
    end-if
    count+=1
  end-do

!writeln(";;;;;;;;;;;;")
!writeln(";;;;;;;;;;;;")

  forall(c in COMMODITIES | test_link(c)>0) do
    if count2=1 then
      writeln("Cost of commodities" + ";" + c + ";" + cost_s(c))
    else
      writeln(";" + c + ";" + cost_s(c))
    end-if
    count2+=1
  end-do

!writeln(";;;;;;;;;;;;")
!writeln(";;;;;;;;;;;;")

  forall(c in COMMODITIES | test_link2(c)>0) do
    if count3=1 then
      writeln("Income from commodities" + ";" + c + ";" + income_s(c))
    else
      writeln(";" + c + ";" + income_s(c))
    end-if
    count3+=1
  end-do

!writeln(";;;;;;;;;;;;")
!writeln(";;;;;;;;;;;;")

  writeln(profit_s)

```

```
fclose(F_OUTPUT)

end-procedure

procedure writeResultsFlow
  declarations
    heading1:   string
    heading2:   string
    flow_s:     dynamic array(PLANTS,PLANTS,COMMODITIES) of string
  end-declarations

heading1:= "Flow pattern in the cluster"
heading2:= "From plant" + ";" + "To plant" + ";" + "Commodity" + ";"
  forall(t in TIME) do
    heading2+= "Flow in period " + t + ";"
  end-do

forall(i in PLANTS, j in PLANTS, c in COMMODITIES | LINKS(i,j,c)=1) do
  flow_s(i,j,c):= i + ";" + j + ";" + c + ";"
    forall(t in TIME) do
      flow_s(i,j,c)+= string(getsol(flow(i,j,c,t)))
      flow_s(i,j,c)+= ";"
    end-do
end-do

fopen("WGMO_Flow.sol",F_OUTPUT)
  writeln(heading1)
  writeln(heading2)
  forall(i in PLANTS, j in PLANTS, c in COMMODITIES | LINKS(i,j,c)=1) do
    writeln(flow_s(i,j,c))
  end-do
fclose(F_OUTPUT)

end-procedure

procedure writeResultsPlants
  declarations
    heading1:     string
    heading2:     string
    capacity_s:     array(PLANTS) of string
    production_s:   array(PLANTS,COMMODITIES) of string
```

```
      resource_s:        array(PLANTS,COMMODITIES) of string
    end-declarations

heading1:= "Results from the plants"
heading2:= "Plant" + ";" + "Category" + ";"
    forall(t in TIME) do
      heading2+= "Period" + t + ";"
    end-do

forall(p in PLANTS) do
    capacity_s(p) += p + ";" + "Installed capacity" + ";" + string(getsol(
        capacity(p))) + ";" + string(getsol(capacity(p)))
end-do

forall(p in PLANTS, c in COMMODITIES | LINKS(p,'MARKET',c)=1) do ! | exists(
    flow(p,'MARKET',c,1))) do
    production_s(p,c) += p + ";" + "Production of " + c + ";"
    forall(t in TIME) do
      production_s(p,c) += string(sum(i in PLANTS) getsol(flow(p,i,c,t))) +
          ";"
    end-do
end-do

forall(p in PLANTS, c in COMMODITIES | LINKS('MARKET',p,c)=1) do ! | exists(
    flow(p,'MARKET',c,1))) do
    resource_s(p,c) += p + ";" + "Use of " + c + ";"
    forall(t in TIME) do
      resource_s(p,c) += string(sum(j in PLANTS) getsol(flow(j,p,c,t))) + ";"
    end-do
end-do

fopen("WGMO_Plants.sol",F_OUTPUT)
    writeln(heading1)
    writeln(heading2)
    forall(p in PLANTS) do
      writeln(capacity_s(p))
    end-do
    forall(p in PLANTS, c in COMMODITIES | LINKS(p,'MARKET',c)=1) do ! |
        exists(flow(p,'MARKET',c,1))) do
      writeln(production_s(p,c))
    end-do
```

```
  forall(p in PLANTS, c in COMMODITIES | LINKS('MARKET',p,c)=1) do ! | exists(flow('MARKET',p,c,1))) do
    writeln(resource_s(p,c))
  end-do
fclose(F_OUTPUT)

end-procedure

!Eugene_Maisiuk. Setting an Adherent Point between WGMO & DDCFA tools
procedure writePlantsCashFlows
  declarations
    heading1:    string
    heading2:    string
    investment_p: array(PLANTS) of string
    oper_cost_p:  dynamic array(PLANTS,COMMODITIES) of string
    input_cost_p: dynamic array(PLANTS,COMMODITIES) of string
    income_p:    dynamic array(PLANTS,COMMODITIES) of string
    profit_p:    dynamic array(PLANTS) of string
  end-declarations

  heading1:= "Cash flows from the plants"
  heading2:= "Plant" + ";" + "Category" + ";" + "Commodity" + ";"
  forall(t in TIME) do
    heading2+= "Period" + t + ";"
  end-do

  !writing out Plant Investment costs.
  forall (p in PLANTS) do
    investment_p(p) += p + ";" +  "Investment costs" + ";" + ";"
    forall (t in TIME) do
      if (t=1) then
        investment_p(p) += string(getsol(inv_plant(p)) * INV_FIXED_COST(p) + getsol(capacity(p)) * INV_UNIT_COST(p)) + ";"
        else
        investment_p(p) += "" + ";" !Assumption: Inv costs occur only in t=1
      end-if
    end-do
  end-do

  !writing out Plant Operational costs
  forall(p in PLANTS, c in COMMODITIES | c = COMM_OPER(p)) do
```

```
    oper_cost_p(p,c) += p+ ";" + "Operation costs of" + ";" + c + ";"
    forall(t in TIME) do
      oper_cost_p(p,c) += string(getsol(OPERATION_COST_PLANT(p,t))) + ";"
    end-do
  end-do

  !writing out Plant Input costs
  forall(p in PLANTS, c in COMMODITIES | LINKS('MARKET',p,c)=1) do
    input_cost_p(p,c) += p + ";" + "Input costs of" + ";" + c + ";"
    forall(t in TIME) do
      input_cost_p(p,c) += string(PURCH_PRICE(c,t)*sum(j in PLANTS) getsol(flow(j,p,c,t))) + ";"
    end-do
  end-do

  forall(p in PLANTS, c in COMMODITIES | LINKS(p,'MARKET',c)=1) do
    income_p(p,c) += p + ";" + "Income from" + ";" + c + ";"
    forall(t in TIME) do
      income_p(p,c) += string(SALES_PRICE(c,t)*sum(i in PLANTS) getsol(flow(p,i,c,t))) + ";"
    end-do
  end-do

  forall (p in PLANTS) do
    profit_p(p) += p + ";" + "Profit" + ";" + ";"
    forall (t in TIME) do
      if t=1 then
        profit_p(p) += string(getsol(REVENUE_FROM_PLANT(p,t))- getsol(OPERATION_COST_PLANT(p,t))-getsol(INVESTMENT_COST_PLANT(p))) + ";"
        else
        profit_p(p) += string(getsol(REVENUE_FROM_PLANT(p,t))- getsol(OPERATION_COST_PLANT(p,t)))+";"
      end-if
    end-do
  end-do

fopen("WGMO_PlantsCashFlows.sol",F_OUTPUT)
  writeln(heading1)
  writeln(heading2)

```

```
  forall(p in PLANTS-{'MARKET'}) do
    writeln(investment_p(p)) !exclude MARKET plant, no need for such data
  end-do

  forall(p in PLANTS, c in COMMODITIES | c = COMM_OPER(p)) do
    writeln(oper_cost_p(p,c))
  end-do

  forall(p in PLANTS, c in COMMODITIES | LINKS('MARKET',p,c)=1) do
    writeln(input_cost_p(p,c))
  end-do

  forall(p in PLANTS, c in COMMODITIES | LINKS(p,'MARKET',c)=1) do
    writeln(income_p(p,c))
  end-do

  forall (p in PLANTS-{'MARKET'}) do !exclude MARKET plant, no need
    writeln (profit_p(p))
  end-do

fclose(F_OUTPUT)
end-procedure
!EndEugene

end-model
```