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Integration of societal outage cost into infrastructure design and maintenance optimisation

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***Abstract*— The paper presents quantitative RAM-based economic models capable of sup-plying early and realistic information on the envisaged lifespan economic perfor-mance of energy infrastructure systems during their conceptual designs. Unlike the conventional cost models which do not take these RAM characteristics into account, the models in this paper provide an early trade-off between the RAM attributes the designer wants to incorporate in the system and the cost of having them. The economic models thus provide the designer the ultimate leeway of selecting more intrinsically reliable and more inherently maintainable components or subsystem of the infrastructure system at a more affordable investment costs. The paper focusses on a user friendly formulation for incorporating the social costs, which are typical for infrastructures that operate in the public domain, in the cost structure of infrastructure systems. To demonstrate the implementation and utility of these economic models, it has been applied to a District Heating Network (DHN) case study.**

I. INTRODUCTION

One of the key aspects of infrastructure systems is their relatively long life span, e.g., several decades. Over this long a time span it is not only that the value of money significantly changes, but also the income from delivered services and goods can change. Furthermore, in keeping up the performance of the infrastructure, several re-investments in new technologies (retrofits) may be necessitated. These require that a life span perspective must be taken in setting up the economic model. Therefore, in most of the cost formulation the discrete lifespan perspective of costs and benefits is the main mathematical structure of the economic model. What is being emphasized in this paper is the fact that the RAM (Reliability, Availability, Maintainability) as well as the economy of the infrastructure system (as infrastructural performance indicators) should be consecutively carried along the length and breadth of the concept and early design phases as well as in the entire life cycle. The overriding importance of integrating such economic performance indicator that takes into account RAM related strategic issues in these specific phases stems from the fact that a very high proportion of the potential to influence life cycle cost and revenue generation of the infrastructure systems is fixed in these phases. This has been extensively discussed in [1][2][3]. Apart from the life cycle perspective, a novel cost formulation that adds the social cost of infrastructure service outages to the RAM-enriched cost equations is the hallmark of this paper. The next section briefly introduces the Markov RAM-based economic models and section III will build upon this model by introducing cost models that reflect the social outages. In section IV, the applicability of the models are demonstrated by means of a case study of a district heating infrastructure design.

II. MARKOV RAM-BASED ECONOMIC MODEL

By Markov RAM-based economic model, we mean a set of mathematical relationships between cost and system design variables, as well as other performance metrics like RAM, which could realistically predict cost and other economic indicators from the values of these variables and metrics.

For instance, from the availability models, the downtime at any given performance level due to failures could be determined and the associated costs and efforts of having such availability as well as the revenue loss accruable to it can be fed into the economic model.

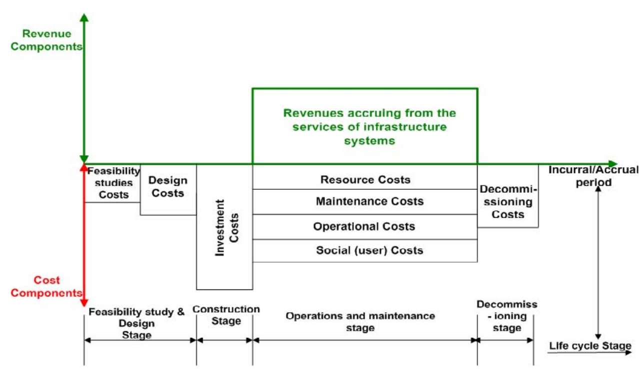

Figure 1 Graphical illustration of the cost and revenue components of a large scale infrastructure system

In Figure 1, the various cost and revenue components as well as the stages in the life cycle of the infrastructure system where such costs and revenues are incurred or accrued are depicted. These costs, especially those incurred at the operations and maintenance stage as well as construction and decommissioning stage, form the major elements of the economic model that have been developed.

We refer to [3] for detailed derivations of the various elements of our cost models. The overall stochastic model comprises the following elements:

- social (user) cost model (see next section)

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- decommissioning cost model (to include nuclear power plant decommissioning)
- resource cost model
- investment cost model
- maintenance cost model (introduces stochastics through RAM)
- revenue model
- Expected cash flow model
- Expected NPV model

The following overall Expected NPV function was developed:

$$E\{NPV\} = \sum_{h=1}^{H} \frac{E\{CF\}_h}{(1+r)^h}$$
$$= \sum_{h=1}^{H} ((1+r)^h)^{-1} E\{R\}_h - E\{C_M\}_h - E\{C_r\}_h$$
$$- \frac{E\{TC_{DD}\}}{H} - E\{C_s\}_h - E\{TC_I\}_h \quad (1)$$

where $E\{CF\}_h$ is the maintainability/reliability accounted for cashflow in year (time interval h), r is the discounted rate (which captures the time value of money) and may represent the ination or interest rate, h is the particular year under consideration and H is the total number of time periods (life cycle of the infrastructure system). With the final economic performance measure-the *E(NPV)*, the design alternatives can always be evaluated economically and the best in terms of the positiveness of the *E(NPV)* is to be chosen for further propagation or design considerations. Having established the *E(NPV)* of the alternatives, the Expected Profitability Index *E(P1)* (equation 2) can as well be used in deciding which project merits further considerations.

$$E(PI) = \frac{E\{NPV\}}{E\{TC_I\}} \quad (2)$$

The *PI* is a ratio of the NPV to the total investment cost TC_I. In the profitability index analysis as well, the business rule is to accept and/or consider projects or investments with profitability index greater than 1. However, the acceptance or rejection of the project using the *PI* rule still largely depends on the risk averseness or otherwise of the stakeholders as well as the nature of portfolio.

The next section elaborates on the development of a social (user) cost model that reflects outages of the infrastructure service.

III. Social (User) Cost Models

Social cost as used in this paper is the cost of a service interruption or the cost to be borne by infrastructure systems providers if the system fail to satisfy any laid down contractual performance level. Such cost may vary from one infrastructure system to another and from one customer to another and may be a function of the impact of the interruption on the customer operations, revenues, and/or direct health and safety. In most conventional process systems, the social or user cost is usually ignored in the cost structure breakdown. This is nonetheless understandable as such systems have minimal interactions with the society at large and as such their downtime does not affect the populace in a direct significant manner. As a result of this, the providers of such process services may be in less stringent spelt-out contractual obligations to pay penalties if they do not live up to the performance expectations . In the infrastructural sectors, the game might be even tighter as providers are often under stringent and regulated contractual obligations to pay penalties in the wake of poor or non-performance. Thus ignoring such social costs may lead to too low and/or optimistic results in the economic model of infrastructure system. This said, it becomes imperative that the social cost of the loss of service or downtime of units be incorporated into the economic models of infrastructure systems. Invoking the concept of multi-state multi-performance models as developed in [3], partial failures and thus the associated social costs in infrastructure systems services or products may still occur even when the system is operating, but then at a reduced performance level.

In the social cost model that follows, the assumption is that the systems or units that are not performing to the contractually agreed performance level, whether fully down or at an unacceptably low level can be lumped together and are expected to attract a societal cost commensurate with the level of loss of function. With this simplification in mind, two performance regimes can be discerned, the contractually non-penalizable performance level and the contractually penalizable performance level.

Let pl^c be the critical performance level (that is the point of transition from the contractually penalizable performance level to the contractually non-penalizable performance level *pl*). Therefore:

$$If \begin{cases} pl > pl^c & \text{then no social cost} \\ pl \le pl^c & \text{then social cost applies} \end{cases} \quad (3)$$

Thus, knowing the cost the infrastructure providers will pay to people as compensations when such unit of the system is down or not performing to agreed contractual level at a given time horizon ψ_{kh}, (in cost per people) and the number of people *N*, affected by the downtime (non-performance) of the unit of the infrastructure system *k* at a given time horizon *h*, N_{kh} (in number of people affected), the frequency at which these non performance of unit *k* occur within a time instance *h*, f_{kh} (in number of occurrence per time) , the duration of the occurrence of non-performance of unit *k* within the time instance *h*, D_{kh} (in time per occurrence) , the expected Social Cost $E(C_S)$ of unit *k* at a given time instance *h* is:

$$E\{C_s\}_h = \sum_{k=1}^{k} A_{kh}(pl \le pl^c)\psi_{kh} N_{kh} f_{kh} D_{kh} \quad (4)$$

$A_{kh}(pl \leq pl^c)$ is the availability at a performance level lower than or equal to the contractually acceptable level. The expected Total Social Cost $E(TC_S)$ of unit k at a given time instance h is modeled as:

$$E\{TC_s\} = \sum_{h=1}^{H}\sum_{k=1}^{k} A_{kh}(pl \leq pl^c)\psi_{kh}N_{kh}f_{kh}D_{kh}$$

$$E\{TC_s\} = \sum_{h=1}^{H}\sum_{k=1}^{k} \{1 - A_{kh}(pl > pl^c)\psi_{kh}N_{kh}f_{kh}D_{kh} \quad (5)$$

The cost the infrastructure providers will pay to people as compensations when a unit or the system is down or not performing to agreed contractual level at a given time horizon (ψ_{kh}), is usually determined or set by law and often described or communicated to the users of such infrastructure systems.

For instance, in the Netherlands, a network operator is required by regulation, to pay some compensation to the consumers in the event of sustained power outage. This compensation is categorized into two cost categories; the non-performance or delivery cost and the damage cost. In the non-performance or delivery cost category, the consumer is to be compensated to the tune of 35 euro in the event of a four-hours-power outage and in the damage cost category, the network operator is obliged to pay the consumers, the cost of the items that gets damaged as a result of the sustained power outage (to a maximum of 200 euro per connection).

To protect the network operators though, the network operator can only expend to a maximum limit of one million euro per incident as compensations for both social cost categories. To establish a link between the probability of non-performance, as expressed by the time fraction of non-availability, and the occurrence (frequency) and duration of an incident (failure), it has been assumed that if there would be a non-performance over an entire standard interval h it is counted as one incident. However, if the frequency and duration is established (from company surveys etc), this assumption could be relaxed, in most cases though, these are very difficult to establish.

The non-performance or delivery cost to a consumer (connection point) per incident may be quite differentiated and may vary from the reliability contract of the consumer with the network-operator. In this case, those with higher reliability contracts may receive more and vice versa [4].

By extension, the estimation of the cost the infrastructure providers will pay to people as compensations when such unit or the system is down or not performing to agreed contractual level at a given time horizon (ψ_{kh}), may vary from one infrastructure systems to another, and from one application area to another (e.g residential, commercial, agricultural, industrial etc) [5] and from one country or region to another. As another example, Pacific Gas & Electric Company (PG&E) researched the estimated direct costs of outages to their customers and showed that cost can vary widely by customer [6]. For industrial customers, this cost range from $12.70 to $428 for every kWh power un-served and for residential customers, this cost ranges from $5.10 to $8.5 for every kWh power un-served. The same goes for other commercial customers whose costs range from $40.60 to $68.2 for every kWh power unserved.

IV. Application of Models: Optimisation Results

A. System description

The low-level temperature industrial waste heat, generated by a pharmaceutical plant in the North of a city, at a temperature of between 25 and 35 °C is routed to a heat upgrading unit where the temperature is raised to the required heat level by heat pumps before being taken to the central grid. To enhance the system effectiveness and flexibility, the steam from the main grid is taken to a modular (district) grid where the possible connection to the dwelling abodes and offices are made as shown in Fig. 2.

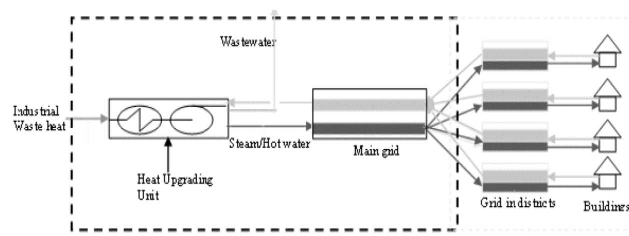

Figure 2. System diagram of the District Heating Network

The low-temperature hot water from the dwellings is again recycled back to the heat upgrading unit for further heat upgrade for better conservation of energy. The distance from the pharmaceutical plant (source of residual waste heat) to the existing dwellings and new areas to be developed ranges from 2 to 6 km. Apart from the moderate heat for the city heating, the system could be tuned such that steam could be produced from the chemical heat pump which could be sold back to the pharmaceutical company or to the power producers to improve the economy of the process. This is important with respect to the maintenance of the turn-down ratio of the system. During the summer when the external temperature is high, the system could be tuned to the production of steam and/or electricity and in so doing, keeping the turn-down ratio at the required level. With this flexibility, the system could handle fluctuations or deviations from one scenario to the other [7].

For each of the cost and revenue models introduced in section III, the associated parameters and costs have been determined. This has been extensively described in [3] and will therefore not be repeated in this paper. The following paragraphs summarize the main assumptions and parameters that were used in the key models.

B. Investment and maintenance cost

Two types of equipment and investment costs have been discerned, the conventional equipment and investment costs and the reliability/maintainability based (RMb)- equipment and investment costs. In the conventional equipment and investment costs, the effects of the inherent reliability and maintainability of the various units and/or subsystems were not taken into account. While in RMb-equipment and investment costs, the inherent reliability and maintainability of the various units and/or subsystems and their associated cost escalation features have been properly taken into account. The conventional equipment and investment cost for the DHN case study was estimated using the Lang method [8]. In table 1, the inherent reliability and maintainability data (reference and desired) for all the major units of the DHN system are given.

Table 1. Reliability/maintainability parameters for *the equipment and investments* cost estimation of the DHN case study

SUB-SYSTEMS	REFERENCE INHERENT RELIABILITY (10^{-6})	DESIRED INHERENT RELIABILIT (10^{-6})	REFERENCE INHERENT MAINTAIN-ABILITY	DESIRED INHERENT MAINTAIN-ABILITY
Heat XRs				
-HE-1	28	2.8	0.8	0.97
-HE-2	28	2.8	0.85	0.98
-HE-3	35	3.5	0.88	0.99
Compressor				
-C1	63	6.3	0.9	0.99
-C2	45	4.5	0.9	0.99
-C3	40	4.0	0.88	0.99
Furnance	30	3.0	0.8	0.97
NH3 Vessel	5	0.5	0.8	0.98
Distribution pump	92	9.2	0.8	0.98
Pipes	7.5	0.75	0.8	0.98
	Reliability-based cost adjustment parameter (α)=0.015 Maintainability-based cost adjustment parameter (β)=10			

The reference inherent reliability or maintainability as used here, is the standard reliability or maintainability the manufactures of equipment are ready to embed into the equipment without demanding further costs from the customers. It may also be defined as the inherent reliability or maintainability originally agreed (between the manufactures and the customers) to be embedded into the equipment during their design and fabrications.

Maintenance cost is an important and contributory element of the cost structure and as well one of the few cost elements often deployed in the early selection of design alternatives. As a result, ways of minimizing it (maintenance cost) early in the design process is always sought. The desired inherent reliability and maintainability chosen early in the conceptual design stage have a great influence in the downside operational stage when maintenance must be initiated. It is expected that an investing more on the inherent reliability and maintainability of a given system will drastically reduce the amount to be spent in the maintenance process. Using the investment and maintenance models developed in [3], the maintenance cost to be consumed in both the conventional and the RMb cases as well as the associated equipment costs were determined. The conventional maintenance cost is always assumed to be 4% of the fixed capital cost [8], therefore, no room is given for the estimation of the costs individual pieces of equipment is to be consumed by virtue of the reliability and maintainability characteristics. The over-arching assumption in the conventional method is that all piece of equipment have the same inherent reliability and maintainability characteristics and equal maintenance costs. This, as helpful as it may seem, does not sound realistic, as various equipment have various inherent characteristics and consume varying maintenance costs. In the model in this paper realistic attempts are made at representing this phenomenon.

The economic models used in this paper produced higher equipment costs and invariably, higher investment cost due to the selection of higher inherently reliable and intrinsically maintainable components for the DHN system design. However, and fortunately, during the operational phase of the infrastructure systems, it is also shown that this high investment cost in higher inherently reliable and intrinsically maintainable components leads to a significant reduction in the system maintenance cost. Putting this in context, comparing the conventional and RMb cases, an equipment cost over-run of about 2.5 million US dollar can be observed. This over-run as said earlier is to make for the selection of inherently reliable and maintainable pieces of equipment. However, if the maintenance cost of both cases is compared, there is a tremendous maintenance cost reduction of approximately 4 million US dollars owing to the investment in these reliable and maintainable units. It can be concluded that from a long term perspective, the overall RAM benefit stands at approximately 2 million US dollars.

C. *Social costs*

Though social costs for the electricity market are readily available in the public domain, such is not the case in the heat market. It was not possible to come by any social cost associated with the DHN in the open literature, neither was it possible to get such information from the DHN operators. The absence of unified regulatory laws in the district heat market in the Netherlands at the time of our research, may have accounted for this. For the aforementioned reasons therefore, it was diffiult to determine with precision, the annualized cost of outages of the DHN case. This does not in any way negate the importance of considering such cost, as the district heat market terrain may change in the near future. However, for the purpose of illustration, engineering judgment has been ap- plied in determining such data. The engineering judgment used in the establishment of the disruption cost of is based on the estimates by [6] which show that for residential customers, this cost ranges from US$5.10 to US$8.5 per kWh. Here it is assumed that for heat disruption or un-served heat, this cost is quite lower (US$26.8 per hour of un-served heat). It is also assumed that about one-tenth of the total number of people (11,000) to be connected to the heat grid will be affected. A total social cost of more than a million US dollar is estimated for this DHN case, see Table 2.

These values are best guesses as the real data can only be obtained through industrial surveys.

Table 2. Estimated annual social cost of the DHN case study

MODEL PARAMETERS	VALUES
Availability at performance level greater than critical	0.938
Heat Quality disruption (availability at or below critical performance)	0.062
Frequency (occurrence per year)	5
Duration per occurrence (hr/occurrence)	12
Disruption Cost per hour (US$ per hr per connection)	26.8
Total Number of connections to be affected (connections)	11,000
Social Cost (10^6US$=yr)	1.097

D. Total production cost

The total production cost for the DHN case study as given in table 3 includes the resource cost, the maintenance, social and otherk operational cost associated with the production of the output heat from the process. The social cost as well as the decommissioning cost(the total decommissioning cost spread over the life span of the DHN here assumed to be 40 years) is being classifed as variable operational costs here since such costs still add up to the final cost of the product being delivered by the process and it may develop and vary over time. A total production cost of about 21 million US dollar per year is estimated using the RMb-models developed in [3] as against the 26 million US dollar per year if the conventional model is used. The difference in both estimates is as a result of the low maintenance cost associated with the early purchase of highly more reliable and maintainable pieces of equipment in the RMb case.

Table 3. Estimated Resource and Production costs for the DHN case study

	CONVENTIONAL	RM-BASED
Resource Costs (x106$/year)	12.904	12.520
Maintenance (x106$/year)	5.14	1.220
Others(x106$/year)	7.40	7.40
Social Cost (x106$/year)	0.977	1.097
Decommissioning cost (x106$/year)	0.019	0.028
Total production cost (x106$/year)	26.43	21.15

E. Revenues

The revenue level accruing to the DHN is a function of the amount of heat that can be sold to the customers and this depends on the size of the district heat system and on climate conditions. It is assumed that about 80 % of the connected households consume less than 119GJ of heat per year and the rest 20% have a consumption pattern greater than or equal to 119 GJ of heat per year. The concept of one-time fee is based on the current norm in the Netherlands where once a customer is connected to a DHN, he has to pay a one-time fee of about 3,700 euro. This amount is mainly used to cover part of the investment of the upgrading unit and the pipelines from this unit to the houses. Also in the estimation, the one time connection fee and the right of usage fee were not levied any form of tax (i.e.VAT of 19% and/or energy tax of 6.32 per GJ does not apply to them). These data was validated with the data from the Website of Euroheat and Power (www:euroheat:org) which stipulates the cost at 11 euros per GJ (VAT excluded).

The total income from the heat sales based on the conventional and the RMb models are 16.4 and 15.3 M$ respectively. The estimated revenue from the conventional model is somewhat higher per annum than estimated using the RMb model. The disparity between the two cases can be explained by the fact that the conventional model assumes a 100% availability of the process while the RMb model takes into account the shortfalls in the availability. This is in line with an earlier work [1] in which it was affirmed that the use of the conventional economic models without recourse to RAM aspects introduces tremendous bias in the overall economic viability of the system.

F. Expected Net Present Value

In table 4, the net present values as well as the profitability index of the DHN case study for both the conventional and RMb models are reported. These were determined from the Expected cash flow model, which was based on the revenues and (stochastic) cost models.

One may question the rationale behind estimating the NPV and PI of systems already yielding negative cash flows. However, one of the major differences between an infrastructure and any other process systems (and the goods and services each produces) is that infrastructures have more public character than many other process systems. Infrastructures goods and services can therefore be regarded as "public goods" for which prices charged, seldom cover the cost of production. It can thus be argued that while projects may be abandoned in many other domains for just turning up negative cash flows, in the infrastructure domain, due to the public nature of the goods and services, and whole lots of other factors (some more politico-social than economic), such project may be taken up irrespective of their negative cash flow. Again, from a more general perspective, if we are considering cases with multiple options, the estimation of their E(NPV)s may reveal better, the cheapest option when compared to other options. And since there may be a strict requirement to deliver, one may be compelled to choose the least bad case. For instance, in the DHN case study, the municipal government who is the expected project owner (and one of the stakeholders) may decide to go ahead with the project (the negative cash flow notwithstanding) because of the DHN great and unavoidable necessity to the society. The DHN systems may also receive direct financial support from the national government and public bodies in cases where such district heating network is needed and desired for political reasons, but is not economically feasible. In such a case, it becomes very necessary to relay to the project owners and other stakeholders , the accumulated loss (negative NPV and PI) they will bear if such project is to be further propagated. In so doing, it gives the owner(s) and other interested stakeholders, more political and financial leverage in making available, any necessary incentives, subsidies and/or tax breaks as well as fund reservations (in case they still want to pursue the project). The results are tabulated in Table 4.

Table 4. Expected NPV for conventional & RMb models.

	CONVENTIONAL	RMB
NPV (*r = 3.5%)*	-235.23	-140.13
PI	-8.03	-4.41

As can be deduced from Table 4, applying the conventional and RMb- models, the municipality will incur an accumulated loss to the tune of 235 and 140 million US dollars respectively throughout the entire life span of the DHN system if they should go ahead with the construction of the system at its present form. Again, though both losses are high, but the loss to be associated with the RMb model is relatively lower. This is also reflected in the relatively higher profitability index (approximately -4) of the RMb model compared to the conventional model (approximately -8).

G. Sensitivity testing

We have subjected our findings to various thorough sensitivity testings. The main ones were sensitivities with respect to the quantity of heat demanded, discount rates, products produced, product prices, resource costs, and selected intrinsic reliabilities. The analyses showed unvaryingly that the RMb model performed better in a life span perspective than the conventional model for cost estimation and profitability analysis.

V. CONCLUSIONS

Infrastructure systems economic performance viewed from more life cycle perspective should start at the conceptual design stage and should account for all costs that will be incurred in the infrastructure systems lifetime. This is against the backdrop that the economic decisions made during the infrastructure system design, may affect its performance-reliability, availability maintainability and even safety-wise and will ultimately determine its price, ownership cost and the overall economic viability. Apart from the usage of RAM-based economic models, the paper focusses on deriving a user friendly formulation for incorporating social costs in the cost structure of infrastructure systems. To demonstrate the implementation and utility of these quantitative RAM-based economic models, it has been applied to the District Heating Network where it is shown that a negative cash flow is obtained if heat only DHN is considered. The paper revealed evidence of better profitability indicators using the RMb-economic metrics over the conventional model. Specifically, approximately 20% reduction in the total production cost can be achieved using the formulated models compared to result of a conventional model. This is made possible by the thorough enhancement of the infrastructure systems long-term RAM attributes early in the infrastructure design stage.

REFERENCES

[1] Ajah, A. N., P. M. Herder, J. Grievink, M. P. C. Weijnen , Integrating flexibility & reliability in the conceptual process designs of networked energy and industrial infrastructures: case study of a district heating system, *Proceedings of World Congress of Chemical Engineering*, Glasgow, Scotland, 2005.

[2] Ajah A. N., J. Grievink, A. Mesbah, P. M. Herder, P.W. Falcao, S. Wennekes , On the Robustness, Effectiveness and Reliability of Chemical & Mechanical Heat pumps for Low Temperature Heat Source District Heating: A Comparative Simulation-based Analysis and Evaluation. *Energy-The International Journal*, Vol 33, issue 6, pp 908-928, 2008

[3] Ajah AN, On the Conceptual Design of Large-scale Process & Energy Infrastructure Systems: Integrating Flexibility, Reliability, Availability, Maintainability and Economics (FRAME) Performance Metrics, PhD dissertation, Delft University of Technology, Delft, 2009

[4] Wijnia Y.C, "Kosten voor consumenten in geval van power outage", e-mail correspondence, 2008

[5] Ajodhia V.S., Regulating Beyond Price: Integrated Price-quality regulation for electricity distribution network, PhD Thesis, Delft University of Technology, 2006

[6] CEC (California Energy Commission), The Cost of Wildlife-Caused Power Outages to California's Economy, Energy and Environmental Economics, CEC Report CEC-500-2005-030, 2005

[7] Ajah A.N., A.C. Patil, P.M. Herder, J. Grievink, Integrated conceptual design of a robust and reliable waste-heat district heating system, *Applied Thermal Engineering Journal*, Vol 27, No. 7, pp 1158-1164, 2007.

[8] Douglas J.M.. , Conceptual Design of Chemical Processes. McGraw-Hill Book Co., Singapore, 1988