



Evaluation of Power Outage Costs for Industrial and Service Sectors in Finland

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Dedicated to

Mustafa SARP

The man who taught me the true meaning of life.

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Abstract			
<p>Electric power business has changed dramatically for the past 30 years. There is a considerable change in the structure and electric power system operation throughout the world. Having an unbundled and competitive electric market, Finland is a proper country to study power outage costs for industrial and service sector customers.</p> <p>An electric power outage, which has many social and most importantly economical outcomes, is an undesired and unpleasant event that leads inevitable damages to the society. Regardless of its psychological effects, preventing power outages presents a vital importance due to its severe effects on economy. Therefore, since it has so many motivating factors, studying and estimating the outage costs have been an attractive and popular field of study for the recent years.</p> <p>There are several methods used in assessing the customer costs of electric power outages. Among all, three major classes; indirect analytical methods, customer surveys and case studies, are commonly used in the power business and academic studies</p> <p>The main purpose of this thesis is to develop a proper mathematical model to be able to reach a conclusion to make estimations about the customer outage costs and to give the utilities and large power consuming customers an idea about these costs. At this point, a way to find out an almost linear model for this problem will be sought.</p>			
Keywords Interruption, Reliability, Outage Cost, CIC, Customer, Utility, Industry Sector, Service Sector.			

Table of Contents

PREFACE.....	V
LIST OF ABBREVIATIONS	VI
LIST OF FIGURES	VII
LIST OF TABLES	XI
1 INTRODUCTION.....	1
1.1 PROBLEM STATEMENT	1
1.2 OBJECTIVE.....	2
2 METHODS OF EVALUATING POWER OUTAGE COSTS.....	3
2.1 INDIRECT ANALYTICAL METHODS	3
2.2 CASE STUDIES.....	3
2.3 CUSTOMER SURVEYS.....	3
2.4 PROPOSED METHODOLOGY	4
3 THE CUSTOMER SURVEY FOR INDUSTRIAL AND SERVICE SECTORS IN FINLAND.....	7
4 EVALUATION OF POWER OUTAGE COSTS FOR INDUSTRIAL SECTOR IN FINLAND.....	8
4.1 UNEXPECTED OUTAGES.....	9
4.2 PLANNED OUTAGES.....	9
4.3 INDUSTRIAL SECTOR POWER OUTAGE COST ANALYSIS	10
4.3.1 Food industry.....	10
4.3.2 Chemical industry	11
4.3.3 Glass industry	13
4.3.4 Paper industry.....	14
4.3.5 Metal industry	16
4.3.6 Timber industry.....	17
4.3.7 Construction industry	19
4.3.8 Electrical industry.....	20
4.3.9 Textile industry.....	22
4.4 Outage Cost Estimation Examples for Industrial Sector.....	23
4.4.1 Example #1	23
4.4.2 Example #2.....	24
4.5 COMMENTS.....	25
5 EVALUATION OF POWER OUTAGE COSTS FOR SERVICE SECTOR IN FINLAND.....	26

5.1	SERVICE SECTOR POWER OUTAGE COST ANALYSIS.....	28
5.1.1	Whole Sale.....	28
5.1.2	Department Store.....	31
5.1.3	Other Retail.....	34
5.1.4	Garage.....	37
5.1.5	Hotel.....	40
5.1.6	Restaurant.....	43
5.1.7	Finance.....	46
5.1.8	Sports.....	49
5.1.9	IT.....	52
5.1.10	Health.....	55
5.1.11	Others.....	58
5.2	Outage Cost Estimation Examples for Service Sector.....	61
5.2.1	Example #1.....	61
5.2.2	Example #2.....	62
5.3	COMMENTS.....	64
6	CONCLUSION.....	65
7	REFERENCES.....	66

PREFACE

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Sinan Küfeoğlu

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LIST OF ABBREVIATIONS

CIC	Customer Interruption Cost
CDF	Customer Damage Function
WTP	Willingness to Pay
WTA	Willingness to Accept
PAM	Preparatory Action Method
DW	Direct Worth Approach

LIST OF FIGURES

Figure 1: unexpected outage cost analysis results for food industry.....	10
Figure 2: planned outage cost analysis results for food industry.....	11
Figure 3: unexpected outage cost analysis results for chemical industry.....	12
Figure 4: planned outage cost analysis results for chemical industry.....	12
Figure 5: unexpected outage cost analysis results for glass industry.....	13
Figure 6: planned outage cost analysis results for glass industry.....	14
Figure 7: unexpected outage cost analysis results for paper industry.....	15
Figure 8: planned outage cost analysis results for paper industry.....	15
Figure 9: unexpected outage cost analysis results for metal industry.....	16
Figure 10: planned outage cost analysis results for metal industry.....	17
Figure 11: unexpected outage cost analysis results for timber industry.....	18
Figure 12: planned outage cost analysis results for timber industry.....	18
Figure 13: unexpected outage cost analysis results for construction industry.....	19
Figure 14: planned outage cost analysis results for construction industry.....	20
Figure 15: unexpected outage cost analysis results for electrical industry.....	21
Figure 16: planned outage cost analysis results for electrical industry.....	21
Figure 17: unexpected outage cost analysis results for textile industry.....	22
Figure 18: planned outage cost analysis results for textile industry.....	23
Figure 19: turnover and u-w-d outage cost analysis results for the Whole Sale sector.....	28
Figure 20: characteristics of u-w-d reported cost / turnover for the Whole Sale sector.....	29
Figure 21: characteristics of planned / unexpected outage costs for the Whole Sale sector.....	29
Figure 22: characteristics of summer / winter outage costs for the Whole Sale sector.....	30
Figure 23: characteristics of outside / during working hours outage costs for the Whole Sale sector.....	30
Figure 24: summary of outage cost characteristics for the Whole Sale sector.....	31
Figure 25: turnover and u-w-d outage cost analysis results for the Department Store sector.....	31
Figure 26: characteristics of u-w-d reported cost / turnover for the Department Store sector.....	32

Figure 27: characteristics of planned / unexpected outage costs for the Department Store sector	32
Figure 28: characteristics of summer / winter outage costs for the Department Store sector.....	33
Figure 29: characteristics of outside / during working hours outage costs for the Department Store sector.....	33
Figure 30: summary of outage cost characteristics for the Department Store sector	34
Figure 31: turnover and u-w-d outage cost analysis results for the Other Retail sector	34
Figure 32: characteristics of u-w-d reported cost / turnover for the Other Retail sector.....	35
Figure 33: characteristics of planned / unexpected outage costs for the Other Retail sector	35
Figure 34: characteristics of summer / winter outage costs for the Other Retail sector.....	36
Figure 35: characteristics of outside / during working hours outage costs for the Other Retail sector.....	36
Figure 36: summary of outage cost characteristics for the Other Retail sector.....	37
Figure 37: turnover and u-w-d outage cost analysis results for the Garage sector.....	37
Figure 38: characteristics of u-w-d reported cost / turnover for the Garage sector	38
Figure 39: characteristics of planned / unexpected outage costs for the Garage sector	38
Figure 40: characteristics of summer / winter outage costs for the Garage sector	39
Figure 41: characteristics of outside / during working hours outage costs for the Garage sector	39
Figure 42: summary of outage cost characteristics for the Garage sector.....	40
Figure 43: turnover and u-w-d outage cost analysis results for the Hotel sector.....	40
Figure 44: characteristics of u-w-d reported cost / turnover for the Hotel sector	41
Figure 45: characteristics of planned / unexpected outage costs for the Hotel sector.....	41
Figure 46: characteristics of summer / winter outage costs for the Hotel sector	42
Figure 47: characteristics of outside / during working hours outage costs for the Hotel sector ..	42
Figure 48: summary of outage cost characteristics for the Hotel sector	43
Figure 49: turnover and u-w-d outage cost analysis results for the Restaurant sector	43
Figure 50: characteristics of u-w-d reported cost / turnover for the Restaurant sector.....	44
Figure 51: characteristics of planned / unexpected outage costs for the Restaurant sector.....	44
Figure 52: characteristics of summer / winter outage costs for the Restaurant sector.....	45
Figure 53: characteristics of outside / during working hours outage costs for the Restaurant sector.....	45

Figure 54: summary of outage cost characteristics for the Restaurant sector.....	46
Figure 55: turnover and u-w-d outage cost analysis results for the Finance sector.....	46
Figure 56: characteristics of u-w-d reported cost / turnover for the Finance sector	47
Figure 57: characteristics of planned / unexpected outage costs for the Finance sector.....	47
Figure 58: characteristics of summer / winter outage costs for the Finance sector	48
Figure 59: characteristics of outside / during working hours outage costs for the Finance sector	48
Figure 60: summary of outage cost characteristics for the Finance sector	49
Figure 61: turnover and u-w-d outage cost analysis results for the Sports sector.....	49
Figure 62: characteristics of u-w-d reported cost / turnover for the Sports sector	50
Figure 63: characteristics of planned / unexpected outage costs for the Sports sector	50
Figure 64: characteristics of summer / winter outage costs for the Sports sector	51
Figure 65: characteristics of outside / during working hours outage costs for the Sports sector	51
Figure 66: summary of outage cost characteristics for the Sports sector	52
Figure 67: turnover and u-w-d outage cost analysis results for the IT sector.....	52
Figure 68: characteristics of u-w-d reported cost / turnover for the IT sector	53
Figure 69: characteristics of planned / unexpected outage costs for the IT sector	53
Figure 70: characteristics of summer / winter outage costs for the IT sector.....	54
Figure 71: characteristics of outside / during working hours outage costs for the IT sector.....	54
Figure 72: summary of outage cost characteristics for the IT sector.....	55
Figure 73: turnover and u-w-d outage cost analysis results for the Health sector	55
Figure 74: characteristics of u-w-d reported cost / turnover for the Health sector.....	56
Figure 75: characteristics of planned / unexpected outage costs for the Health sector	56
Figure 76: characteristics of summer / winter outage costs for the Health sector	57
Figure 77: characteristics of outside / during working hours outage costs for the Health sector	57
Figure 78: summary of outage cost characteristics for the Health sector	58
Figure 79: turnover and u-w-d outage cost analysis results for the other sectors.....	58
Figure 80: characteristics of u-w-d reported cost / turnover for the other sectors.....	59
Figure 81: characteristics of planned / unexpected outage costs for the other sectors	59
Figure 82: characteristics of summer / winter outage costs for the other sectors	60

Figure 83: characteristics of outside / during working hours outage costs for the other sectors60

Figure 84: summary of outage cost characteristics for the other sectors 61

LIST OF TABLES

Table 1: coefficients of the unexpected and planned outage cost estimations for the food industry	10
Table 2: coefficients of the unexpected and planned outage cost estimations for the chemical industry	11
Table 3: coefficients of the unexpected and planned outage cost estimations for the glass industry	13
Table 4: coefficients of the unexpected and planned outage cost estimations for the paper industry	14
Table 5: coefficients of the unexpected and planned outage cost estimations for the metal industry	16
Table 6: coefficients of the unexpected and planned outage cost estimations for the timber industry	17
Table 7: coefficients of the unexpected and planned outage cost estimations for the construction industry	19
Table 8: coefficients of the unexpected and planned outage cost estimations for the electrical industry	20
Table 9: coefficients of the unexpected and planned outage cost estimations for the textile industry	22

1 INTRODUCTION

1.1 PROBLEM STATEMENT

Electric power business has changed dramatically for the past 30 years. There is a considerable change in the structure and electric power system operation throughout the world. As it is the case in Finland, in many countries, vertically integrated traditional system consisting of generation, transmission, distribution and retail at one hand, as a monopoly actually, has gone through unbundling. By this way, the system has been decomposed into separate and distinct utilities which perform just a single function of the whole power system. Electric power utilities are highly affected by this change in terms of structure, operation and regulation. These changes are more severe in countries which have competitive markets and highly developed systems. The main objective of a modern and developed electric power system is to provide adequate electrical supply to its customers with close considerations of economical and reliability issues.

The term reliability has a broad and general meaning. It includes load or demand-side measures such as quality and continuity of service as understood by the customer. It also includes utility or supply side concerns such as present and future energy reserves and operational constraints, like equipment ratings and system stability limits, which are not directly seen by the customers [1].

An electric power outage, which has many social and most importantly economical outcomes, is an undesired and unpleasant event that leads inevitable damages to the society. Regardless of its psychological effects, preventing power outages presents a vital importance due to its severe effects on economy. Therefore, since it has so many motivating factors, studying and estimating the outage costs have been an attractive and popular field of study for the recent years. Nonetheless, although there are many studies and researches on reliability cost analysis, the problem is that, there is no rigid and exact method that estimates true economical outcomes of an outage perfectly. To find a solution and to develop a methodology for estimating outage costs, one should answer these questions first;

“What are the consequences of a power outage?”

“What is the worth of the power reliability?”

In terms of customer point of view, the reliability is understood as the continuity of service. Even though there are certain standards for the utilities to supply electric power, most of the customers are only interested in the availability of the supply. Relatively fewer numbers of customers seek for more serious quality requirements such as voltage sags and frequency variations. So the value of the continuity of supply, and therefore the cost of a power outage changes from customer to customer regarding the needs of that particular customer. On the other hand, from the point of view of electric utilities, service reliability means more investment since it requires more and high quality electrical equipment, higher number of employees and capacity margins. As the dependency to the electric power increases and the continuity of supply is seen almost a “right”, the demands of customers who ask for higher quality service even with more costs conflict with those whose primary interest is lower costs even with bad reliability. Utility companies are responsible to find out an optimum solution while considering the balance between the economic benefits that the improvements in

service reliability and quality bring to customers and the costs of these improvements [2]. Nevertheless, in this thesis, the reliability assessment will be done only regarding the customer side point of view.

The costs of power outages change widely with respect to the outage duration, customer type, and frequency of interruption. Furthermore, the geographical location and thus the climate seem to have a big influence on the customer interruption costs (CIC). In southern and western Finland the costs are relatively higher than those are in northern and eastern part of the country. Moreover, at the customers who are fed via underground cables, the CICs are higher than the ones connected to the overhead line networks [3].

While assessing the cost of power outages, there are two main challenges; the first one is the method of collecting the required data, and the second one is the way of evaluating these data.

1.2 OBJECTIVE

One of the most challenging parts of estimating outage costs is the way of collecting the most accurate data. There are several ways of doing it worldwide. Analytical methods is the one way which uses electricity price and the loss of value added of the customer to estimate the outage costs. Another way is the case studies which is used after large blackouts. This is pretty accurate method in case of the direct costs; however, for the calculation of the indirect costs, this method fails to achieve the desired goals. The mentioned methods above are quite tedious and low accurate ways. The most common method that is used widely is the customer surveys. Although it is quite expensive, difficult to handle and it requires too much time and effort to collect, the data of customer surveys are being considered as the most accurate ones [4]. To follow the most reliable way, by one-to-one interviews, telephone calls and e-mail questionnaires, the power outage cost information had been collected by a previous study conducted at Aalto University, School of Electrical Engineering. The whole data used in this thesis is based on the mentioned study. There are two main sectors are of interest of this study, namely; industrial and service sectors.

The service sector subcategories are as follows: whole sale, other retail, garage, hotel, restaurant, finance, sports, IT, health and others.

The industrial sector subcategories are: food, chemical, glass, paper, metal, timber, construction, electrical, textile and others.

The main purpose of this thesis is to develop a proper mathematical model to be able to reach a conclusion to make estimations about the customer outage costs and to give the utilities an idea about these costs. At this point, a way to find out an almost linear model for this problem will be sought.

2 METHODS OF EVALUATING POWER OUTAGE COSTS

There are several methods used in assessing the customer costs of electric power outages. Among all, three major classes are commonly used in the power business and academic studies [4].

2.1 INDIRECT ANALYTICAL METHODS

In indirect analytical methods, generally objective data, namely electricity prices or tariffs, value added of a related company, gross national product of a country and the annual electricity consumption of that country or region is used [1]. To assess the interruption cost, the value of the lost leisure time is considered in the residential customers. For instance, to find out the interruption cost of a given region or country, the annual gross national product is divided by the total electrical consumption. The resulting ratio (\$/kWh) gives a rough idea about the cost of the outage. Customer Damage Function (CDF) is defined as to show the economic loss incurred by the customers due to power outages. It is defined as financial amount of damage against per outage, per kWh of unsupplied energy or per kWh annual consumption of energy [5]. In indirect analytical analysis CDF is generally used to give an idea about the loss of the economic value.

Indirect analytical method is very advantageous because it contains publicly declared, easy to reach and most importantly objective data like electricity prices and turnovers. In addition, it is quite straightforward to apply and a cheaper method to find out the outage costs. On the other hand, however, besides its advantages there are severe disadvantages as well. This methodology presents too broad and average results while utilities seek for specific and customer based results. Furthermore, having neither value added nor gross product, calculating residential outage costs is difficult and subjective. Henceforth, the results generated by indirect analytical methods are not completely useful to the utilities for their planning purposes [4].

2.2 CASE STUDIES

The case studies are carried out after large and significant blackouts. This type of study covers both direct and indirect costs of interruption. Direct costs include loss of sales, loss of food, etc. and the collected data is quite accurate to be made use of in the study. On the other hand, indirect costs include emergency costs and losses due to civil disorder during the outage. In fact, these costs are really difficult to determine, but studies show that they are higher than the direct costs [6]. Being conducted after a real interruption, this method has the advantage of collecting more accurate data. However, the frequency of the large blackout events and the difficulty to make an analogy between large blackouts and small scale blackouts make the case studies disadvantageous to be applied.

2.3 CUSTOMER SURVEYS

Among all, customer surveys have been the most preferred methodology for calculating outage costs. In the survey, there are questions about estimating the outage costs due to interruptions at several time durations at different times of the day (during working hours and outside working hours) and different times of the year (summer and winter). What makes this method superior to the other two is that it provides more accurate and sufficient outage cost data for planning purposes [7]. However, there are major disadvantages of this method. The most important one is its cost. Since the number of responses at the customer side to such surveys is low, in order to get more accurate data, the questionnaire must be done to as many customers as possible. The other drawback is its requirement of high effort to collect the necessary data. These surveys are conducted by one-to-one interviews, telephone calls, and sending and receiving e-mails.

There are three major research methods used in customer surveys, namely, preparatory action method, direct worth approach and the price proportional method [8].

Preparatory action method (PAM) is a direct method that evaluates the costs in terms of avoiding the harm of interruption. Direct worth approach (DW) or direct costing is a method that presents different outage scenarios and asks the customers to estimate a rough cost in case of the scenarios [7]. The price proportional method is a direct method as well. It contains willingness to pay (WTP) and willingness to accept (WTA) methods. In WTP the survey asks the customers that how much they are willing to pay for continuity of service or to avoid a predefined outage. On the other hand, in WTA, the survey asks the customers how much they are willing to be paid in case of a worse reliability of electric distribution system or in case of a predefined outage [9]. Studies show that there is a considerable gap between WTP and WTA results. The respondents are demanding more compensation while they are ready to pay less money for the same outage scenario. This is why the WTP and WTA results are not used alone in the outage cost evaluation.

2.4 PROPOSED METHODOLOGY

When the present technology is considered, by doing one-to-one interviews conducted by professionals, by making telephone calls, and by sending and receiving e-mails, making outage cost surveys for large industrial and commercial facilities is quite expensive. Furthermore the work load is heavy and tedious. Hence, to overcome this problem, a new methodology which is cheaper and easier to conduct is necessary for the assessment of CIC.

In this thesis, a new methodology that comprises with indirect analytical methods and customer surveys has been derived. A linear model based on analytical methods with the aid of a comprehensive customer survey has been developed. The main problem in the customer surveys, as it is discussed previously, is its subjectivity. Naturally people and companies have the tendency of exaggerating their losses in case of an interruption incident. This fact leads questions about the accuracy and reliability of the customer surveys while calculating the true costs of outages. It is almost certain that for a defined interruption scenario, the real cost of the interruption is lower than the answers that are given by the correspondents of the survey. On the other hand, indirect analytical methods propose an objective and easy to reach data such as value added, turnover or annual electricity consumption. By having these properties, indirect analytical methods seem to be superior to the customer surveys. Nevertheless, the researches show that the results of such methods are not sufficient alone to compute the power outage costs. One can ask the following

question; “In case of an interruption, does the loss of a factory just equal to the loss of production at that time period of the outage, or is it more?” obviously the answer is more.

There are many factors affecting the customer interruption costs. The duration of the interruption, the character of interruption (whether it is unexpected or planned), the time that the interruption happens (whether it is at during working hours or outside working hours), the season (summer or winter), and finally the type of the customer (industrial, service, residential or agricultural) are of most importance among all factors. Firstly, as the duration of the interruption increases, naturally the cost of that interruption increases as well. According to the study conducted by Ernest Orlando Lawrence, Berkeley National Laboratory, customer interruption costs increase almost linearly for the first eight hours, and then decreases for the longer outages [10]. Since the purpose of this thesis is to find a linear model for calculating power outage costs in Finland, and since, due to increased reliability in distribution systems, the most of the power outages endure less than eight hours, in this study, only first eight hours of the power outage (1 hour, 4 hours and 8 hours) have been considered. Secondly, the character of the power interruption plays a key role in evaluation as well. An unexpected outage and a planned outage are not the same for the customers. Certainly a customer takes measures if he/she knows the exact time when the outage will happen and how long that outage will last. As a result, the cost of a planned outage will be lower than that of an unexpected outage. Thirdly, for industrial and service sector loads, the time that the interruption occurs is very important in terms of electricity consumption. It is obvious that these facilities use most of their electric power during their working hours. The consumption is expected to be minimum outside working hours, which is clearly seen at the survey results. However, this phenomenon is not valid for the residential loads since there is no such thing as working or outside working hours in these loads. Fourthly, the season plays a crucial role in power interruptions as well. Finland has a cold climate and heating is a major issue in the country. Statistics show that, during winters electricity consumption in residential and industrial facilities increases dramatically. However, at the end of the survey, it is clear that the electricity consumption of some service sector facilities is higher in summers than that of winters. This fact is reasonable because, due to its geographical position, there are big duration differences of day times between summer and winter, and the service sector could said to be working more during summers in Finland. The last but not the least, the type of the customer is a critical parameter while the customer surveys are being conducted. For the utilities, large industrial and commercial facilities are quite problematic while considering utility planning, calculating customer interruption costs for investment and doing operation planning. There is an increasing dependency of large industrial and commercial facilities to electrical and electronic equipment, which makes these facilities be more dependent to the reliability and the quality of the power supplied by electric utilities. When the amount of the power being used by these facilities is considered, the dependency to the reliability is understood better. That is why, the cost of an outage and power quality problems for the industrial and commercial facilities are far higher than those of smaller customers. The rate could be expected to be in orders of magnitude [11]. The method of estimating the outage costs of these customers should be more sophisticated. There are a few numbers of such large customers connected to the transmission lines or to the primary distribution feeder. The power consumption definitely changes in considerable amounts among these customers regarding the size, the production amount, the field that the company works in and the equipments that are being used by those facilities. Therefore, while estimating outage costs for the large industrial and commercial facilities for utility planning purposes, using average cost estimation techniques is not advised. Instead of using average values, each individual industrial and commercial sector must be analyzed separately [12]. During our survey the customers are divided into two main categories, namely, industrial and service sector categories. And then, due to the reasons explained above, with the consideration of the field that are being worked and regarding their power consumption characteristics, the facilities are divided into subcategories.

- i. The industrial sector subcategories are: food, chemical, glass, paper, metal, timber, construction, electrical, textile and others.
- ii. The service sector subcategories are as follows: whole sale, other retail, garage, hotel, restaurant, finance, sports, IT, health and others.

In this thesis, the outage cost characteristics of each subcategory has been studied and analyzed separately and the results are published uniquely.

For the residential customers the way of research differs. Although most of the loads which are being fed by the utilities are residential, it is quite troublesome to estimate the interruption costs of these customers. In case of a blackout, surely there is some amount of economic loss in the domestic users. A fundamental question arises now; "How much does a household loose during a one-hour blackout?" The economic value of the spoiled equipment, such as a broken washing machine due to an outage could be measured. However, how can someone measure the economic value of a lost social activity? For instance, if some user misses a hokey match of his/her favorite team on the television because of an interruption, how much compensation does he/she deserve for that loss of leisure activity? Since one can not mention a certain value added or a turnover for the residential customers and since the worth of lost activities changes from individual to individual, it is quite problematic to evaluate the outage costs of these customers. That is why; this thesis omits the residential customers, and focuses only on the evaluation of the power outage costs for industrial and service sector facilities.

3 THE CUSTOMER SURVEY FOR INDUSTRIAL AND SERVICE SECTORS IN FINLAND

The power consumption and thus outage cost characteristics of each industrial and service sector changes considerably. While preparing the customer survey, this fact and the factors which have been explained at the Proposed Methodology section have been taken into account.

The questionnaire for the industrial sector includes the following data:

- Annual energy consumption.
- Value added per year.
- Cost estimation for 1 hour, 4 hours and 8 hours unexpected outages.
- Cost estimation for 1 hour, 4 hours and 8 hours planned outages.
- The percentage of production losses for 1 hour, 4 hours and 8 hours outages.
- The percentage of restart losses for 1 hour, 4 hours and 8 hours outages.
- The percentage of spoiled material losses for 1 hour, 4 hours and 8 hours outages.
- The percentage of damages for 1 hour, 4 hours and 8 hours outages.
- The percentage of third party losses for 1 hour, 4 hours and 8 hours outages.
- The percentage of other costs for 1 hour, 4 hours and 8 hours outages.

The questionnaire for the service sector includes the following data:

- Annual energy consumption.
- Turnover per year.
- Cost estimation for 1 hour, 4 hours and 8 hours unexpected outages at during working hours.
- Cost estimation for 1 hour, 4 hours and 8 hours unexpected outages at outside working hours.
- Cost estimation for 1 hour, 4 hours and 8 hours planned outages at during working hours.
- Cost estimation for 1 hour, 4 hours and 8 hours planned outages at outside working hours.
- Cost estimation for 1 hour, 4 hours and 8 hours unexpected outages in summer.
- Cost estimation for 1 hour, 4 hours and 8 hours unexpected outages in winter.
- Cost estimation for 1 hour, 4 hours and 8 hours planned outages in summer.
- Cost estimation for 1 hour, 4 hours and 8 hours planned outages in winter.

The customer survey was carried out diligently with great care by doing on site interviews, telephone calls and by highly dense e-mail traffic. The responses from the customers were analyzed and sorted out carefully. The resulting data has been used to form a basis to establish a methodology to bridge between indirect analytical methods and customer survey methods to estimate power outage costs for industrial and service sector in Finland.

4 EVALUATION OF POWER OUTAGE COSTS FOR INDUSTRIAL SECTOR IN FINLAND

Having an unbundled and competitive electric market, Finland is a proper country to study power outage costs for industrial and service sector customers. In this thesis, since the power consumption and operations natures of the customer types are distinct, two different approaches are being developed for the industrial and service sector respectively based on a large and comprehensive customer survey conducted by the researchers at the Aalto University School of Electrical Engineering. During the customer survey, the industrial sector subcategories in Finland for the study had been chosen as: food industry, chemical industry, glass industry, paper industry, metal industry, timber industry, construction industry, electrical industry, textile industry and others.

As it was mentioned previously, in this thesis, the main effort was made on finding out a rigid, linear mathematical method for evaluating power outage costs for large electric power consumers, with the aid of the comprehensive customer survey study results, by using publicly available, objective and easy to reach data.

The industrial customers declare their financial reports to the government each year. The information at these reports are clear, correct, easy to reach and most importantly objective. At this study customer damage function (CDF) was defined as the ratio of the value added for a certain customer for a given time of period to the annual energy consumption corresponding to that time of period. The unit is € / kWh. The load duration time was chosen to be 3000 h per year [3]. As the value added per year (€), the annual energy consumption (kWh) and the load duration time (3000 h) is known for each sector, value added per hour can be calculated easily.

$$\text{Value added per } x \text{ hour} = (\text{value added per year} / 3000 \text{ h}) * x$$

By the aid of the survey, each respondent was asked to estimate his/her amount of power outage cost in Euros for different time periods (for 1 h, 4 h and 8 h). And then a new CDF was defined as:

$$\text{Reported cost per } x \text{ hour} = (\text{cost estimation for period } x)$$

In an industrial facility, when there is continuity of supply, consequently, there is continuous production. And this production is linearly related to the value added that the facility produces. To illustrate:

$$\text{Production} \sim \text{Value added}$$

After calculating the Value added per x hour and Reported cost per x hour, these functions are divided by annual energy consumption of the corresponding customers to get new CDFs, which are:

$$\text{Value added} = (\text{Value added per } x \text{ hour}) / (\text{Annual energy consumption}) \text{ in } \text{€} / \text{kWh}$$

$$\text{Reported cost} = (\text{Reported cost per } x \text{ hour}) / (\text{Annual energy consumption}) \text{ in } \text{€} / \text{kWh}$$

Now the unexpected and planned outage cost characteristics will be analyzed separately.

4.1 UNEXPECTED OUTAGES

As it is the case in the survey, the outage losses comprise of production losses, restart losses, spoiled material losses, third party costs, damages and other costs. Thus we may deduce that, in order to find the linear relationship between Value added per hour and the CIC, we can assign a coefficient K1 which is the ratio of production losses to the total losses. Therefore:

$$K1 = 100 / (\text{percentage of production losses})$$

Where;

Total losses (100%) = production losses + restart losses + losses of spoiled materials + damages + third party costs + other costs

As a result, for the unexpected outages:

$$\text{CIC} = K1 * \text{Value added}$$

After reaching this conclusion, the data of Value added is weighted by the coefficients of the each type of industry. After that, the CIC results, Value added and Estimated cost results are plotted on the graph papers. Finally, by the aid of the linear regression analysis, the linear formulas of each data series have been found.

The graph characteristics, coefficients and formulas will be evaluated and discussed at the Comments section.

4.2 PLANNED OUTAGES

For the planned outage case, the formula of the coefficient differs. When the facility is informed beforehand about a planned interruption, the customer takes measures to minimize his/her losses. These measures include preventing losses of spoiled materials, damages, third party costs and other costs. In case of a previously informed outage, the only losses that the industrial customer suffers will be the production losses and restart losses. So, by following this logic, another coefficient, K2, for planned outages is determined:

$$K2 = (\text{perc. of production losses} + \text{perc. of restart losses}) / (\text{perc. of production losses})$$

Where,

Total losses (100%) = production losses + restart losses + losses of spoiled materials + damages + third party costs + other costs

As a result, for the planned outages:

$$\text{CIC} = K2 * \text{Value added}$$

Again, the CIC results, Value added and Estimated cost results are plotted on the graph papers. By the aid of the linear regression analysis, the linear formulas of each data series have been found.

The graph characteristics, coefficients and formulas will be evaluated and discussed at the Comments section.

4.3 INDUSTRIAL SECTOR POWER OUTAGE COST ANALYSIS

4.3.1 FOOD INDUSTRY

	1 h	4 h	8 h	average
K1	1.9608	2.0121	2.0000	1.9910
K2	1.0980	1.0503	1.0450	1.0645

TABLE 1: COEFFICIENTS OF THE UNEXPECTED AND PLANNED OUTAGE COST ESTIMATIONS FOR THE FOOD INDUSTRY

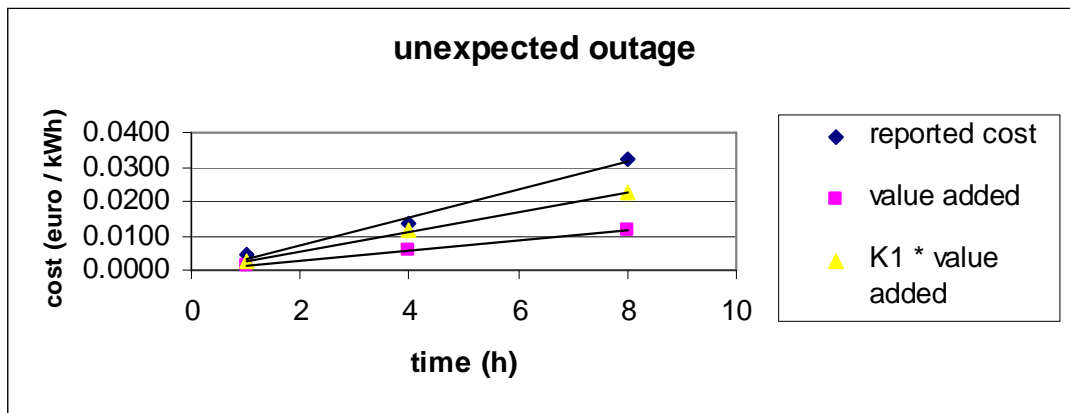


FIGURE 1: UNEXPECTED OUTAGE COST ANALYSIS RESULTS FOR FOOD INDUSTRY

Reported cost: $y = 0.0040x - 0.0007$ $R^2 = 0.9897$

K1 * value added: $y = 0.0029x - 0.0001$ $R^2 = 1$

Value added: $y = 0.0014x$ $R^2 = 1$

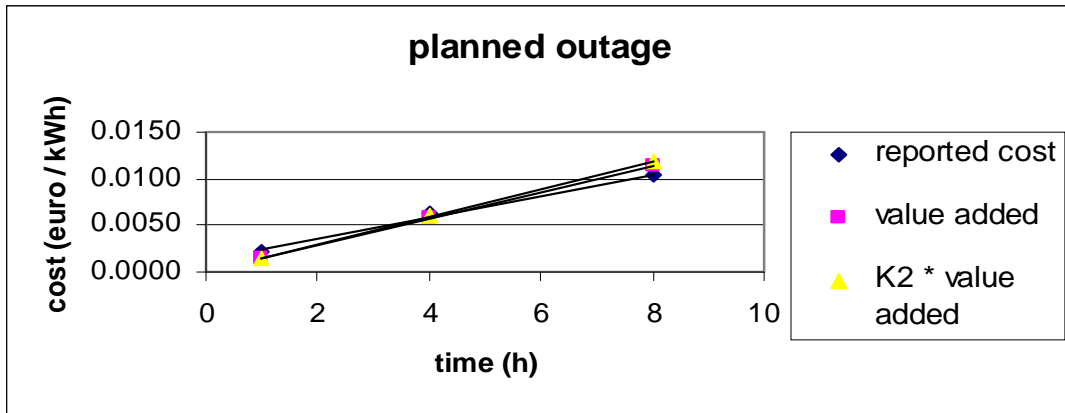


FIGURE 2: PLANNED OUTAGE COST ANALYSIS RESULTS FOR FOOD INDUSTRY

Reported cost: $y = 0.0012x + 0.0013$ $R^2 = 0.9901$

K2 * value added: $y = 0.0015x + 0.0001$ $R^2 = 1$

Value added: $y = 0.0014x$ $R^2 = 1$

4.3.2 CHEMICAL INDUSTRY

	1 h	4 h	8 h	average
K1	3.4783	2.1739	1.8750	2.5091
K2	1.9565	1.4435	1.5344	1.6448

TABLE 2: COEFFICIENTS OF THE UNEXPECTED AND PLANNED OUTAGE COST ESTIMATIONS FOR THE CHEMICAL INDUSTRY

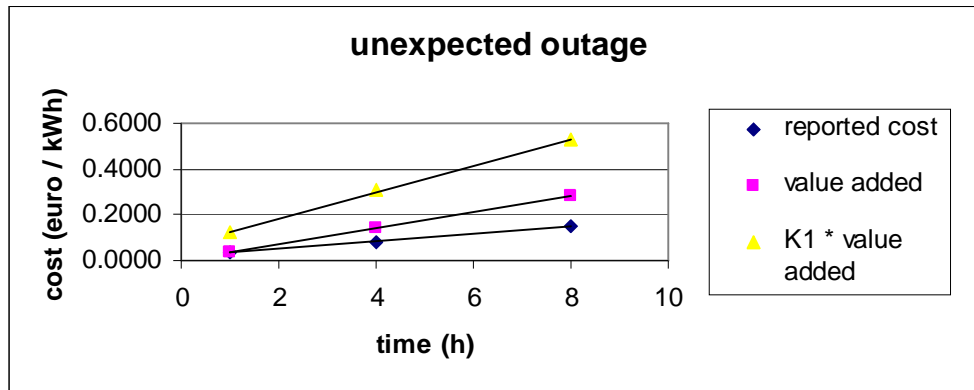


FIGURE 3: UNEXPECTED OUTAGE COST ANALYSIS RESULTS FOR CHEMICAL INDUSTRY

Reported cost: $y = 0.0161x + 0.0198$ $R^2 = 0.9996$

K1 * value added: $y = 0.0580x + 0.0685$ $R^2 = 0.9992$

Value added: $y = 0.0353x$ $R^2 = 1$

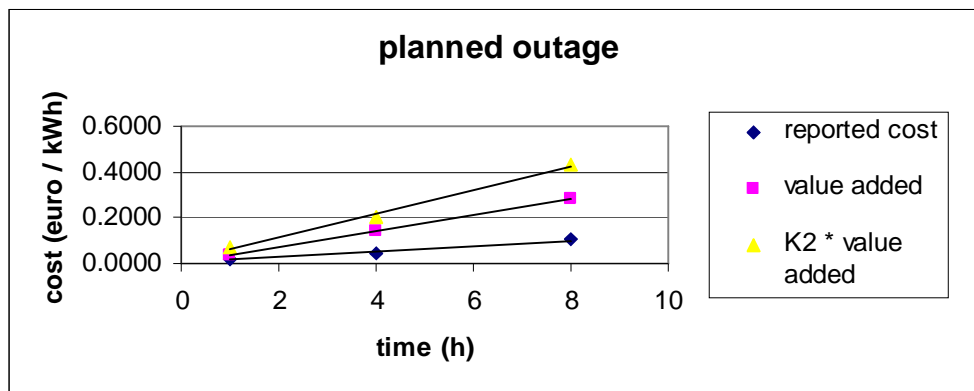


FIGURE 4: PLANNED OUTAGE COST ANALYSIS RESULTS FOR CHEMICAL INDUSTRY

Reported cost: $y = 0.0120x + 0.0027$ $R^2 = 0.9638$

K1 * value added: $y = 0.0523x + 0.0087$ $R^2 = 0.9956$

Value added: $y = 0.0353x$ $R^2 = 1$

4.3.3 GLASS INDUSTRY

	1 h	4 h	8 h	average
K1	2.3739	1.9108	1.7910	2.0253
K2	1.4481	1.1051	1.0657	1.2063

TABLE 3: COEFFICIENTS OF THE UNEXPECTED AND PLANNED OUTAGE COST ESTIMATIONS FOR THE GLASS INDUSTRY

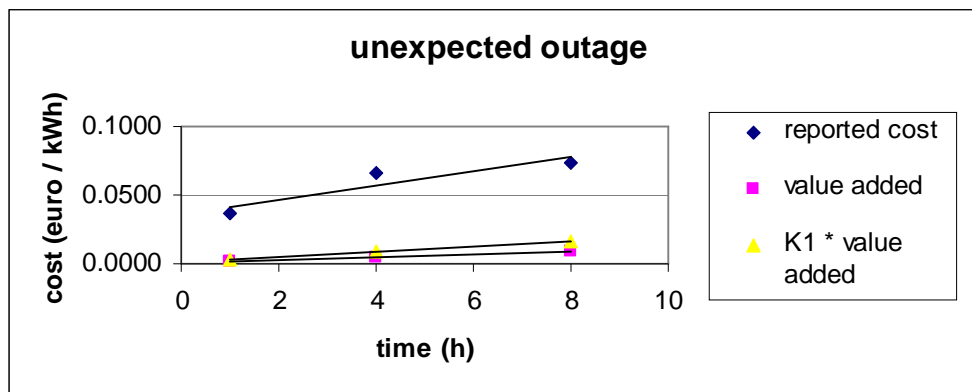


FIGURE 5: UNEXPECTED OUTAGE COST ANALYSIS RESULTS FOR GLASS INDUSTRY

Reported cost: $y = 0.0051x + 0.0365$ $R^2 = 0.8518$

K1 * value added: $y = 0.0018x + 0.0008$ $R^2 = 9998$

Value added: $y = 0.0011x + 0.0001$ $R^2 = 1$

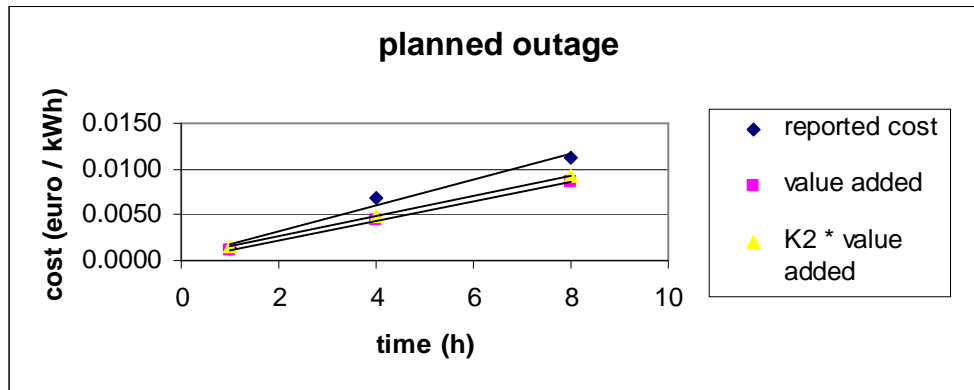


FIGURE 6: PLANNED OUTAGE COST ANALYSIS RESULTS FOR GLASS INDUSTRY

Reported cost: $y = 0.0014x + 0.0003$ $R^2 = 0.9799$

K2 * value added: $y = 0.0011x + 0.0004$ $R^2 = 0.9999$

Value added: $y = 0.0011x + 0.0001$ $R^2 = 1$

4.3.4 PAPER INDUSTRY

	1 h	4 h	8 h	average
K1	1.8576	1.7241	1.5831	1.7216
K2	1.3034	1.2557	1.2296	1.2629

TABLE 4: COEFFICIENTS OF THE UNEXPECTED AND PLANNED OUTAGE COST ESTIMATIONS FOR THE PAPER INDUSTRY

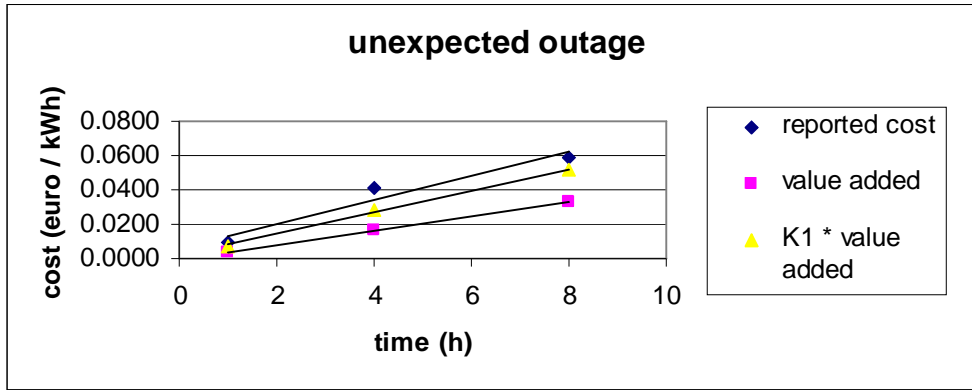


FIGURE 7: UNEXPECTED OUTAGE COST ANALYSIS RESULTS FOR PAPER INDUSTRY

Reported cost: $y = 0.0069x + 0.0066$ $R^2 = 0.9379$

K1 * value added: $y = 0.0063x + 0.0019$ $R^2 = 0.9981$

Value added: $y = 0.0041x$ $R^2 = 1$

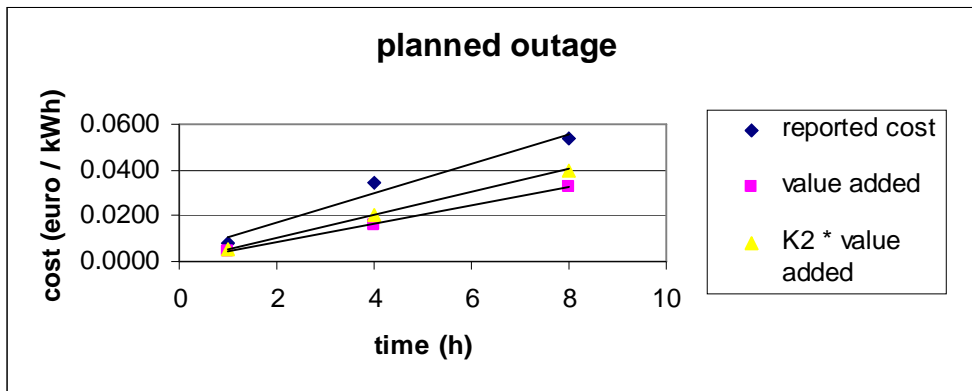


FIGURE 8: PLANNED OUTAGE COST ANALYSIS RESULTS FOR PAPER INDUSTRY

Reported cost: $y = 0.0064x + 0.0041$ $R^2 = 0.9742$

K2 * value added: $y = 0.0050x + 0.0004$ $R^2 = 0.9999$

Value added: $y = 0.0041x$ $R^2 = 1$

4.3.5 METAL INDUSTRY

	1 h	4 h	8 h	average
K1	1.8735	1.6118	1.5596	1.6816
K2	1.2338	1.0610	1.0513	1.1154

TABLE 5: COEFFICIENTS OF THE UNEXPECTED AND PLANNED OUTAGE COST ESTIMATIONS FOR THE METAL INDUSTRY

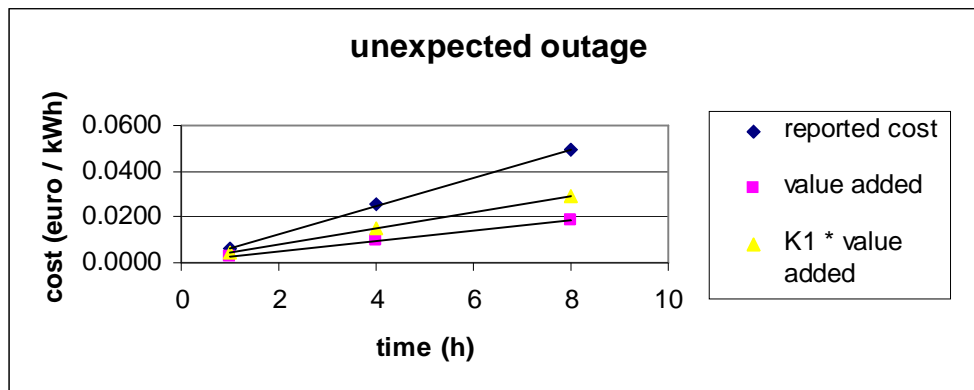


FIGURE 9: UNEXPECTED OUTAGE COST ANALYSIS RESULTS FOR METAL INDUSTRY

Reported cost: $y = 0.0062x + 0.0002$ $R^2 = 0.9995$

K1 * value added: $y = 0.0036x + 0.0009$ $R^2 = 1$

Value added: $y = 0.0023x$ $R^2 = 1$

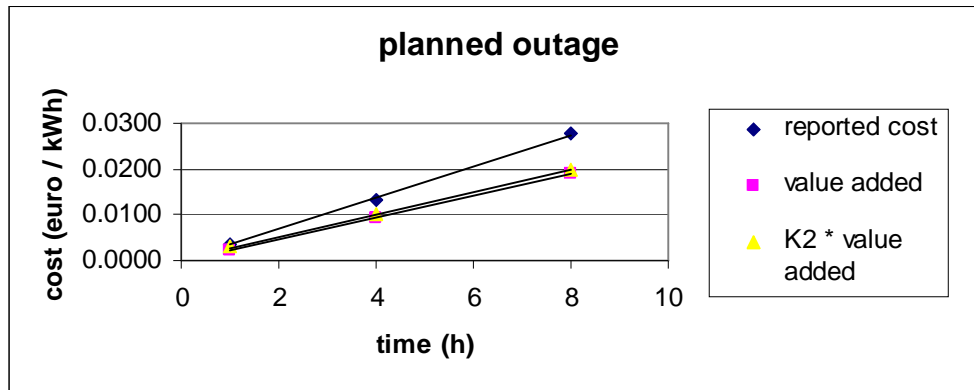


FIGURE 10: PLANNED OUTAGE COST ANALYSIS RESULTS FOR METAL INDUSTRY

Reported cost: $y = 0.0034x - 0.0001$ $R^2 = 0.9981$

K2 * value added: $y = 0.0024x + 0.0004$ $R^2 = 1$

Value added: $y = 0.0023x$ $R^2 = 1$

4.3.6 TIMBER INDUSTRY

	1 h	4 h	8 h	average
K1	1.7094	1.5152	1.3216	1.5154
K2	1.2970	1.1785	1.0837	1.1864

TABLE 6: COEFFICIENTS OF THE UNEXPECTED AND PLANNED OUTAGE COST ESTIMATIONS FOR THE TIMBER INDUSTRY

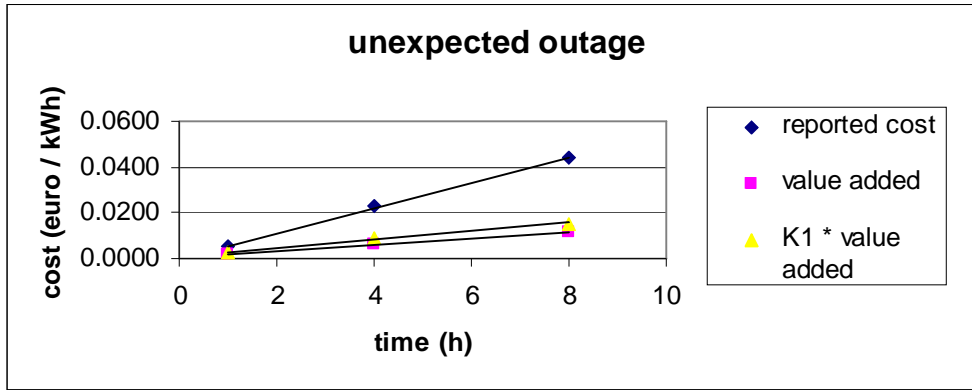


FIGURE 11: UNEXPECTED OUTAGE COST ANALYSIS RESULTS FOR TIMBER INDUSTRY

Reported cost: $y = 0.0055x - 0.0001$ $R^2 = 0.9993$

K1 * value added: $y = 0.0018x + 0.0010$ $R^2 = 0.9949$

Value added: $y = 0.0014x$ $R^2 = 1$

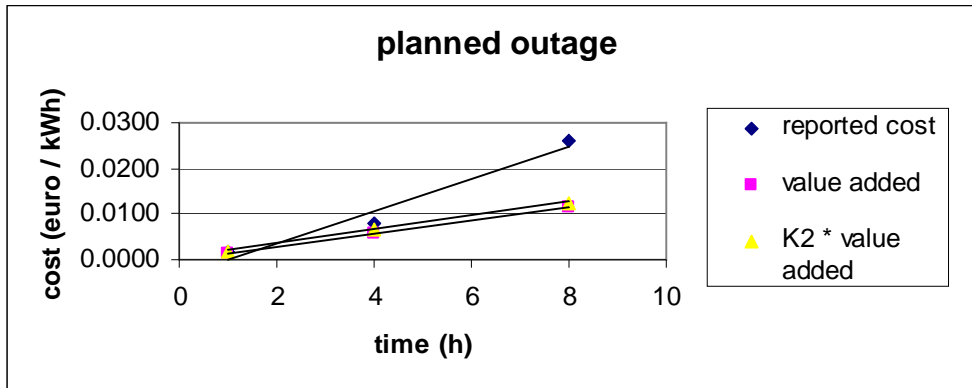


FIGURE 12: PLANNED OUTAGE COST ANALYSIS RESULTS FOR TIMBER INDUSTRY

Reported cost: $y = 0.0035x - 0.0035$ $R^2 = 0.9644$

K2 * value added: $y = 0.0015x + 0.0005$ $R^2 = 0.9984$

Value added: $y = 0.0014x$ $R^2 = 1$

4.3.7 CONSTRUCTION INDUSTRY

	1 h	4 h	8 h	average
K1	1.4260	1.3120	1.3120	1.3500
K2	1.1622	1.1545	1.1545	1.1571

TABLE 7: COEFFICIENTS OF THE UNEXPECTED AND PLANNED OUTAGE COST ESTIMATIONS FOR THE CONSTRUCTION INDUSTRY

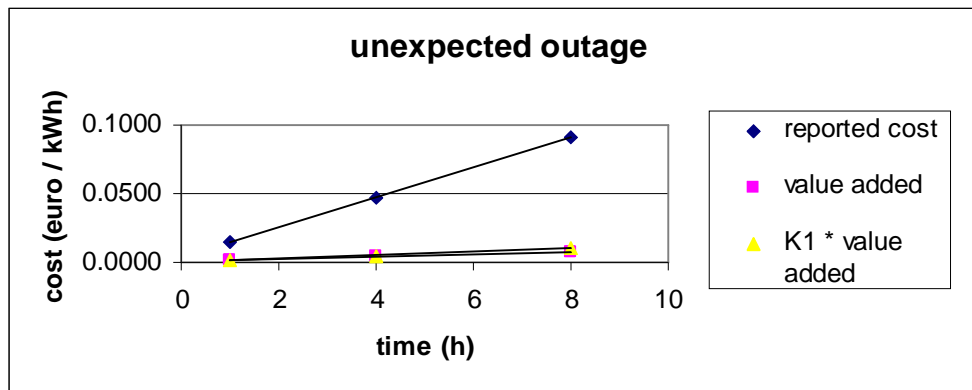


FIGURE 13: UNEXPECTED OUTAGE COST ANALYSIS RESULTS FOR CONSTRUCTION INDUSTRY

Reported cost: $y = 0.0109x + 0.0038 \quad R^2 = 1$

K1 * value added: $y = 0.0012x + 0.0001 \quad R^2 = 0.9999$

Value added: $y = 0.0010x + 0.0001 \quad R^2 = 1$

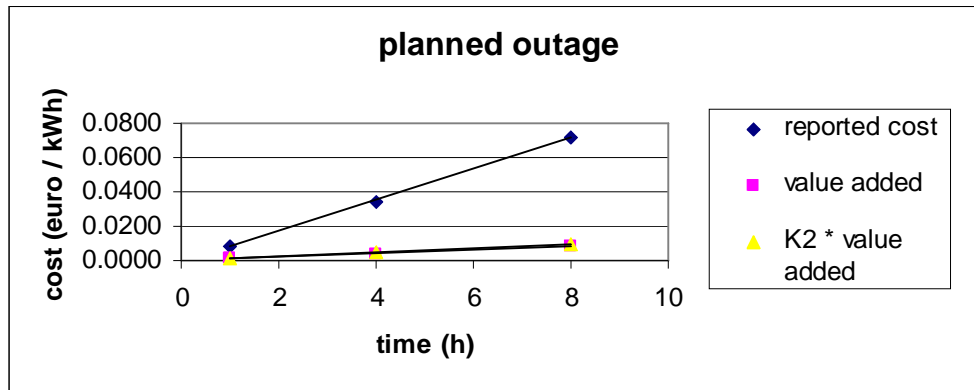


FIGURE 14: PLANNED OUTAGE COST ANALYSIS RESULTS FOR CONSTRUCTION INDUSTRY

Reported cost: $y = 0.0091x - 0.0013$ $R^2 = 0.9987$

K2 * value added: $y = 0.0011x + 0.0001$ $R^2 = 1$

Value added: $y = 0.0010x + 0.0001$ $R^2 = 1$

4.3.8 ELECTRICAL INDUSTRY

	1 h	4 h	8 h	average
K1	1.7073	1.6092	1.4737	1.5967
K2	1.2073	1.0805	1.0526	1.1135

TABLE 8: COEFFICIENTS OF THE UNEXPECTED AND PLANNED OUTAGE COST ESTIMATIONS FOR THE ELECTRICAL INDUSTRY

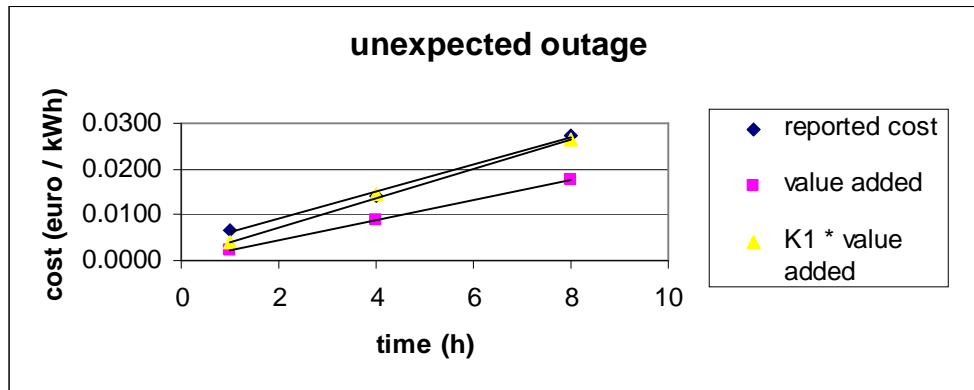


FIGURE 15: UNEXPECTED OUTAGE COST ANALYSIS RESULTS FOR ELECTRICAL INDUSTRY

Reported cost: $y = 0.0030x + 0.0031$ $R^2 = 0.9927$

K1 * value added: $y = 0.0032x + 0.0010$ $R^2 = 0.9978$

Value added: $y = 0.0022x$ $R^2 = 1$

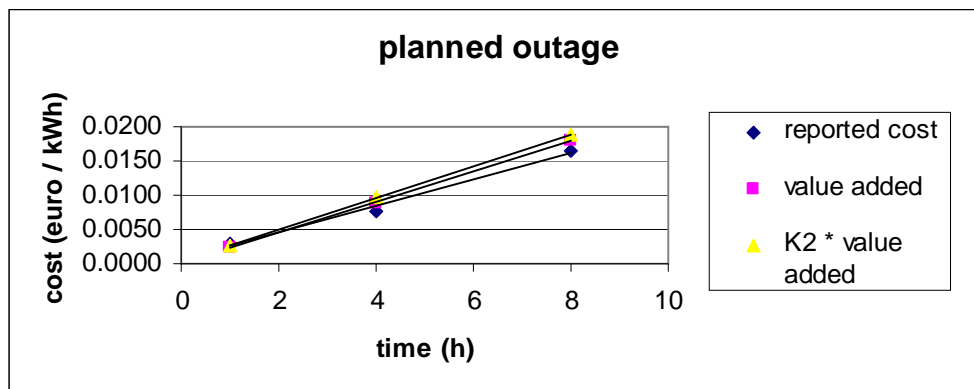


FIGURE 16: PLANNED OUTAGE COST ANALYSIS RESULTS FOR ELECTRICAL INDUSTRY

Reported cost: $y = 0.0019x + 0.0006$ $R^2 = 0.9895$

K2 * value added: $y = 0.0023x + 0.0004$ $R^2 = 1$

Value added: $y = 0.0022x$ $R^2 = 1$

4.3.9 TEXTILE INDUSTRY

	1 h	4 h	8 h	average
K1	1.6667	1.2500	1.1494	1.3554
K2	1.6667	1.2500	1.1494	1.3554

TABLE 9: COEFFICIENTS OF THE UNEXPECTED AND PLANNED OUTAGE COST ESTIMATIONS FOR THE TEXTILE INDUSTRY

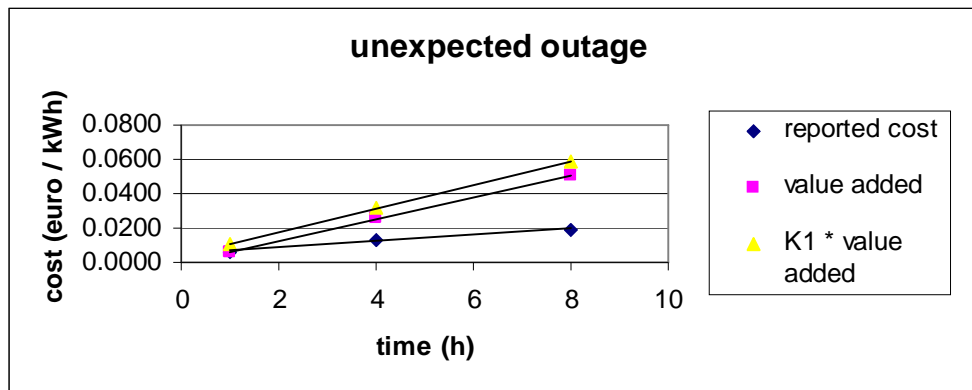


FIGURE 17: UNEXPECTED OUTAGE COST ANALYSIS RESULTS FOR TEXTILE INDUSTRY

Reported cost: $y = 0.0018x + 0.0050$ $R^2 = 0.9932$

K1 * value added: $y = 0.0068x + 0.0040$ $R^2 = 0.9997$

Value added: $y = 0.0064x$ $R^2 = 1$

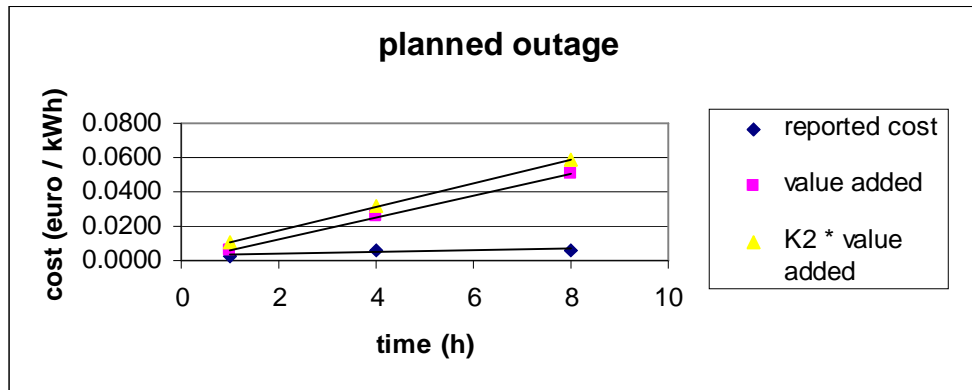


FIGURE 18: PLANNED OUTAGE COST ANALYSIS RESULTS FOR TEXTILE INDUSTRY

Reported cost: $y = 0.0005x + 0.0029$ $R^2 = 0.6757$

K2 * value added: $y = 0.0068x + 0.0040$ $R^2 = 0.9997$

Value added: $y = 0.0064x$ $R^2 = 1$

* Since the number of respondents of the Textile industry sector in the survey is insufficient, the results presented for this sector of industry are not reliable!

4.4 OUTAGE COST ESTIMATION EXAMPLES FOR INDUSTRIAL SECTOR

4.4.1 EXAMPLE #1

In a certain region, an unexpected power interruption occurs, and it lasts for half an hour. An industrial facility in the food sector experiences this outage. The utility supplying the electric power of that region wants to make a rough estimation of this outage quickly. So, what is the customer interruption cost of this facility?

The whole data that is needed to estimate the outage cost is presented. The industry type and the interruption duration are given;

The type of the industry: Food industry

The duration of the interruption: 0.5 h

The characteristics of the interruption: unexpected outage

Now, from the food industry analysis results, the CIC is given as;

K1 * value added: $y = 0.0029x - 0.0001$

Where function y is the power outage cost, and x is the variable denoting outage time. So:

$$\text{CIC} = 0.0029 * 0.5 - 0.0001 = 0.00135 \text{ € / kWh}$$

Since the CIC is known, now the utility can convert this result by multiplying it by the annual energy consumption of the corresponding customer. Since the annual energy consumption data is an objective and easy to reach data, the utility will reach an idea about the loss of that customer in a very short time period.

4.4.2 EXAMPLE #2

In a certain region, the utility informs a customer, which is in the electrical industry sector, that there will be a power interruption between 15.00 and 16.45 o'clock due to maintenance reasons for the following day. The professionals working for this electrical industry company wants to find out how much they will lose due to this power outage.

The summary of the given information:

The type of the industry: Electrical industry

The duration of the interruption: 1.75 h

The characteristics of the interruption: planned outage

Now, from the electrical industry analysis results, the CIC is given as;

K2 * value added: $y = 0.0023x + 0.0004$

Then,

$$\text{CIC} = 0.0023 * 1.75 - 0.004 = 0.003625 \text{ € / kWh}$$

Let us assume that the annual energy consumption of this company is 100 000 kWh, then:

$$\text{CIC} = 0.003625 \text{ € / kWh} * 100\,000 \text{ kWh} = 362.5 \text{ €}$$

4.5 COMMENTS

While doing this study, it was quite obvious and normal that the Reported costs are exaggerated and higher than the actual CIC values. On the other hand, the results obtained from the Analytical method, Value added, were expected to be far lower than the Reported costs. At the end of the analysis of industrial power outage costs this expectation is confirmed. In order to get a more reasonable and more accurate data, some weighing factors were sought with the aid of the questions presented to the respondents during the survey. The logic of finding weighing factors for unexpected and planned outages is coming from the loss percentage data. As it is explained in the above sections, the coefficients are as follows:

$$K1 = 100 / (\text{percentage of production losses})$$

$$K2 = (\text{perc. of production losses} + \text{perc. of restart losses}) / (\text{perc. of production losses})$$

Total losses (100%) = production losses + restart losses + losses of spoiled materials + damages + third party costs + other costs

When the results are observed, according to the analysis, one can see that the average value of K1 roughly equals to 2, while the average of K2 is slightly above 1. And corresponding CIC results are more reasonable than those of customer damage functions of Value added.

The results of this study are quite straightforward and easy to understand. When the professionals working for a utility want to find out the power outage cost for a certain time period for a certain region, they can make use of the formulas presented at this study. As they know how many and what kind of customers are being fed from their power system, for the investment, maintenance or fine paying reasons, they can reach rough but reliable enough customer interruption cost results without making big, comprehensive and most importantly very expensive customer surveys. Likewise, from the point of view of industrial customers, they can estimate their economic losses in case of either unexpected or planned outages easily via this study.

5 EVALUATION OF POWER OUTAGE COSTS FOR SERVICE SECTOR IN FINLAND

During the customer survey, the industrial sector subcategories in Finland for the study had been chosen as: whole sale sector, other retail sector, garage sector, hotel sector, restaurant sector, finance sector, sports sector, IT sector, health sector and others. The service sector analysis and evaluation of the power outage costs are more difficult than those of industrial sectors. This is because, one can not speak of a continuous production and thus a value added linearly proportional to this production in service sector. For instance, a restaurant might be open for a day long and it might consume electricity during this time; however, the income of that restaurant might not be equal for the previous day, in which it consumed the same amount of energy. This fact forces the researchers use average values for the service sector analysis. In addition, in case of a power interruption, a customer, a hotel for example, can continue its function almost without any major losses. Nevertheless, a bank or a company working for IT sector is more dependent on supply reliability when compared to the others. On the other hand, these customers are more dependent on interruption time, climate and interruption characteristics than the customers of industrial sector. As a result, the analysis of power outage costs for service sector is heavier and more difficult than that of industrial sector. The customer survey includes questions regarding the specifications explained above. The respondents are asked to estimate their outage costs for different conditions. The changing parameters are the interruption time (1h, 4h, and 8h), the season (summer, winter) and the interruption characteristics (planned, unexpected). The respondents answered the following questions:

- Cost estimation for 1 hour, 4 hours and 8 hours unexpected outages at during working hours.
- Cost estimation for 1 hour, 4 hours and 8 hours unexpected outages at outside working hours.
- Cost estimation for 1 hour, 4 hours and 8 hours planned outages at during working hours.
- Cost estimation for 1 hour, 4 hours and 8 hours planned outages at outside working hours.
- Cost estimation for 1 hour, 4 hours and 8 hours unexpected outages in summer.
- Cost estimation for 1 hour, 4 hours and 8 hours unexpected outages in winter.
- Cost estimation for 1 hour, 4 hours and 8 hours planned outages in summer.
- Cost estimation for 1 hour, 4 hours and 8 hours planned outages in winter.

In the industrial sector survey we saw that the Reported costs CDF results are higher than the Valueadded CDF results of each industry type. However, the case for the service sector is just the opposite. At each sector type, except for the hotel and sports sectors, the turnovers are higher than the reported outage cost estimations. This means a customer damage function as $\text{Turnover} / \text{kWh}$ can not be used to estimate the power outage costs for this case. Instead, we have to trust to the estimated cost values reported by the respondents. When the parameters affecting the outage costs are being considered, to avoid ambiguity, a straightforward and easy methodology was designed.

As it is in the case for industrial sector analysis, some customer damage functions are defined by the use of the analytical data.

Turnover per x hour = (Turnover per year / 3000 h) * x

Reported cost per x hour = (cost estimation for period x)

Turnover = (Turnover per x hour) / (Annual energy consumption) in € / kWh

Reported cost = (Reported cost per x hour) / (Annual energy consumption) in € / kWh

In Finland, the winters last longer than the summers, so the probability of the occurrence of an interruption event is higher for winters. On the other hand, the electricity consumption, hence the cost of an interruption is higher during working hours than the cost of an interruption outside working hours. Finally, and most importantly, the interruption cost of an unexpected outage is higher than that of a planned outage. By considering the above reasons, the worst case scenario, and the base case for estimating power outage costs for industrial sector in Finland based on the customer survey was chosen to be an unexpected outage, in winter and during working hours. From now on we will use the parameters with their assigned symbols which are designated below:

u: unexpected outage

p: planned outage

w: winter outage

s: summer outage

o: outside working hours outage

d: during working hours outage

The methodology can be explained as follows:

- i. Among the subcategories, choose the type of the sector in which the outage happened.
- ii. The unexpected-winter-during working hours outage characteristics has been plotted and then by the aid of the linear regression, a linear formula representing this outage cost characteristics has been defined for each subcategory. Put the outage time duration into the formula and find out corresponding cost estimation.
- iii. According to the outage characteristics, decide which ratio to be used to convert u-w-d cost to the desired type of cost.

For instance, if the outage is a planned-winter-during working hours one, follow the parameters from left to right to convert your u-w-d cost estimation into p-w-d cost estimation. Multiply your u-w-d cost with the corresponding ratios and finally, obtain p-w-d cost estimation result.

To obtain p-w-d cost from u-w-d cost, one needs to multiply the base cost by p/u ratio. To do this, first go to the corresponding table, in which there are two characteristics: during working hours and

outside working hours. Since the final aim is to find the cost estimation of p-w-d, one needs to choose the ratio characteristics of during working hours. At each multiplication of ratios, put the outage time duration into the corresponding ratio formula, and then multiply your base cost estimation.

By following these steps and using the tables and formulas given below, one can find proper outage cost estimation for the desired service sector easily.

For the observation reasons, the relationships between turnovers and u-w-d costs for each sector have been illustrated as well.

5.1 SERVICE SECTOR POWER OUTAGE COST ANALYSIS

5.1.1 WHOLE SALE

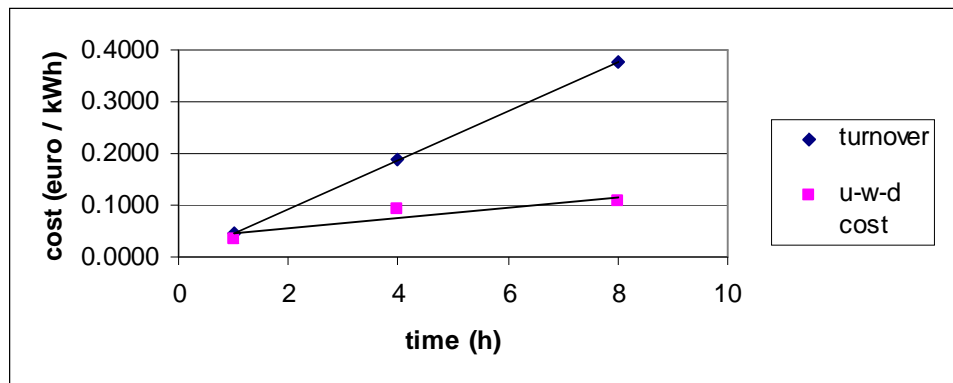


FIGURE 19: TURNOVER AND U-W-D OUTAGE COST ANALYSIS RESULTS FOR THE WHOLE SALE SECTOR

Linear regression results:

Turnover: $y = 0.0472x + 1E-16 \quad R^2 = 1$

Reported u-w-d cost: $y = 0.0102x + 0.0351 \quad R^2 = 0.8606$

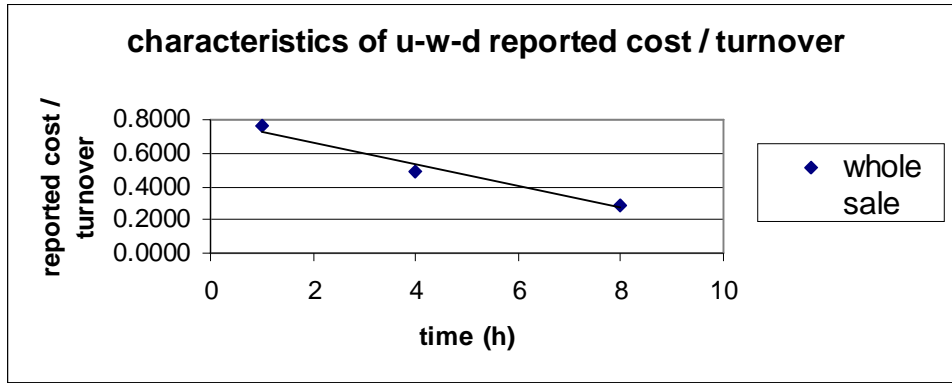


FIGURE 20: CHARACTERISTICS OF U-W-D REPORTED COST / TURNOVER FOR THE WHOLE SALE SECTOR

u-w-d reported cost / turnover : $y = -0.0661x + 0.7988 \quad R^2 = 0.9716$

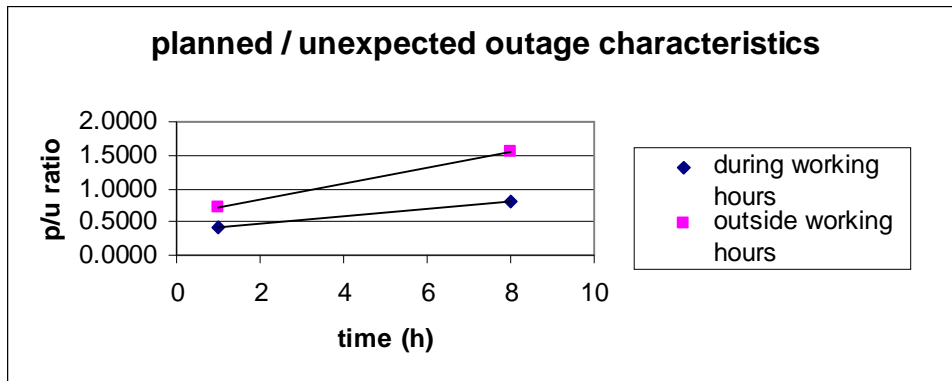


FIGURE 21: CHARACTERISTICS OF PLANNED / UNEXPECTED OUTAGE COSTS FOR THE WHOLE SALE SECTOR

p/u ratio during working hours: $y = 0.0563x + 0.3626 \quad R^2 = 1$

p/u ratio outside working hours: $y = 0.1192x + 0.5834 \quad R^2 = 1$

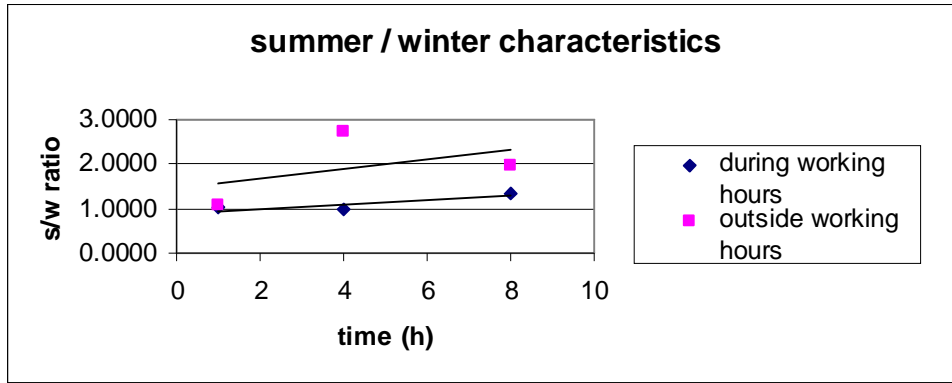


FIGURE 22: CHARACTERISTICS OF SUMMER / WINTER OUTAGE COSTS FOR THE WHOLE SALE SECTOR

s/w ratio during working hours: $y = 0.0501x + 0.9030 \quad R^2 = 0.7282$

s/w ratio outside working hours: $y = 0.1073x + 1.4625 \quad R^2 = 0.2107$

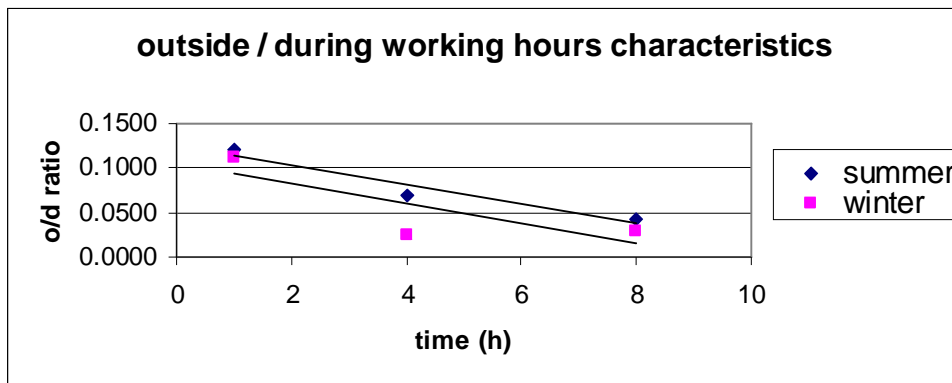


FIGURE 23: CHARACTERISTICS OF OUTSIDE / DURING WORKING HOURS OUTAGE COSTS FOR THE WHOLE SALE SECTOR

o/d ratio in the summer: $y = -0.0108x + 0.1242 \quad R^2 = 0.9371$

o/d ratio in the winter: $y = -0.0111x + 0.1041 \quad R^2 = 0.6308$

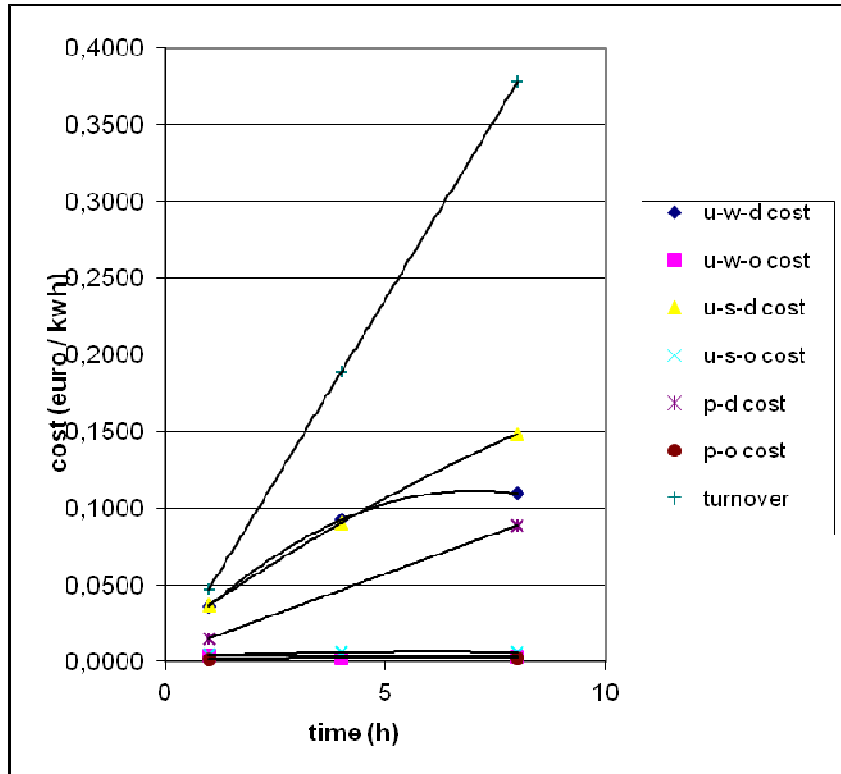


FIGURE 24: SUMMARY OF OUTAGE COST CHARACTERISTICS FOR THE WHOLE SALE SECTOR

5.1.2 DEPARTMENT STORE

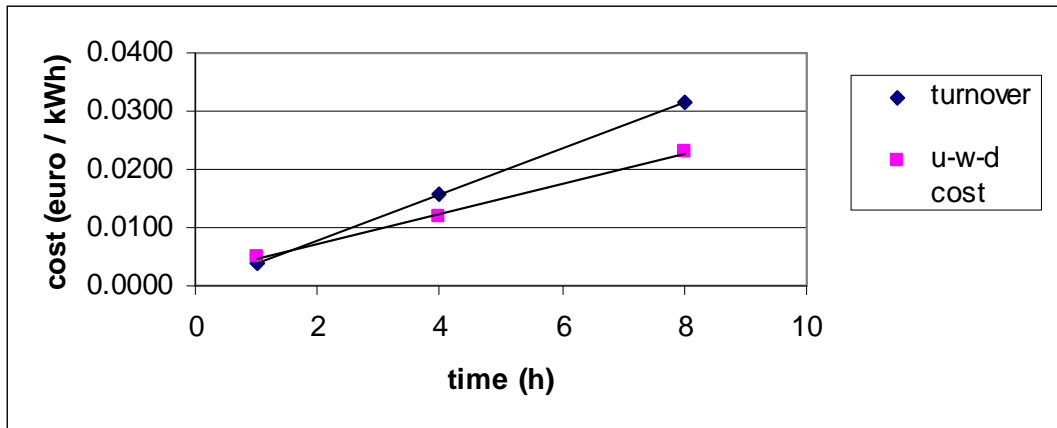


FIGURE 25: TURNOVER AND U-W-D OUTAGE COST ANALYSIS RESULTS FOR THE DEPARTMENT STORE SECTOR

Linear regression results:

Turnover: $y = 0.0039x$ $R^2 = 1$

Reported u-w-d cost: $y = 0.0026x + 0.0020$ $R^2 = 0.9965$

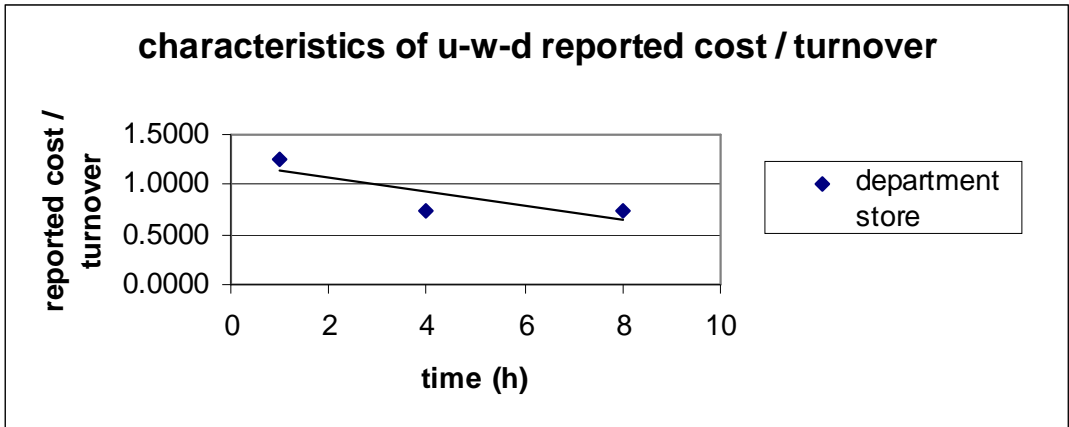


FIGURE 26: CHARACTERISTICS OF U-W-D REPORTED COST / TURNOVER FOR THE DEPARTMENT STORE SECTOR

u-w-d reported cost / turnover : $y = -0.0720x + 1.2233 \quad R^2 = 0.7006$

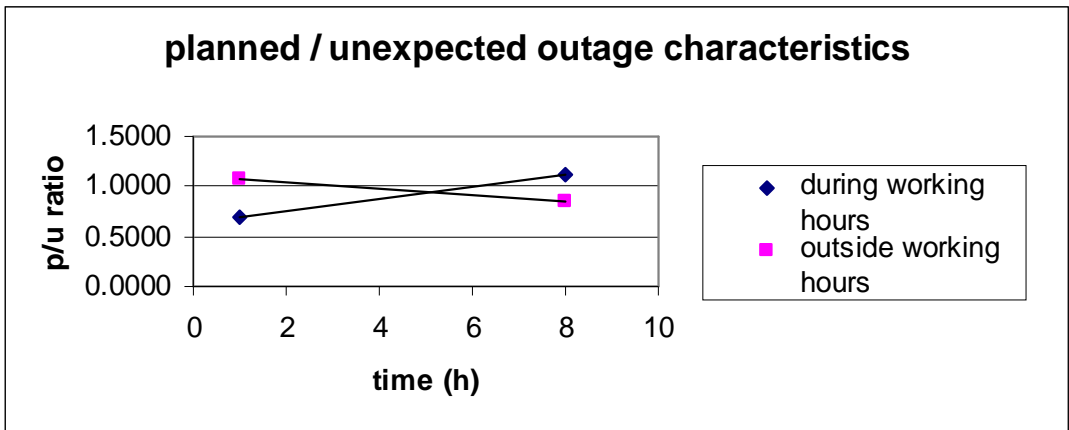


FIGURE 27: CHARACTERISTICS OF PLANNED / UNEXPECTED OUTAGE COSTS FOR THE DEPARTMENT STORE SECTOR

p/u ratio during working hours: $y = 0.0624x + 0.6208 \quad R^2 = 1$

p/u ratio outside working hours: $y = -0.0312x + 1.1070 \quad R^2 = 1$

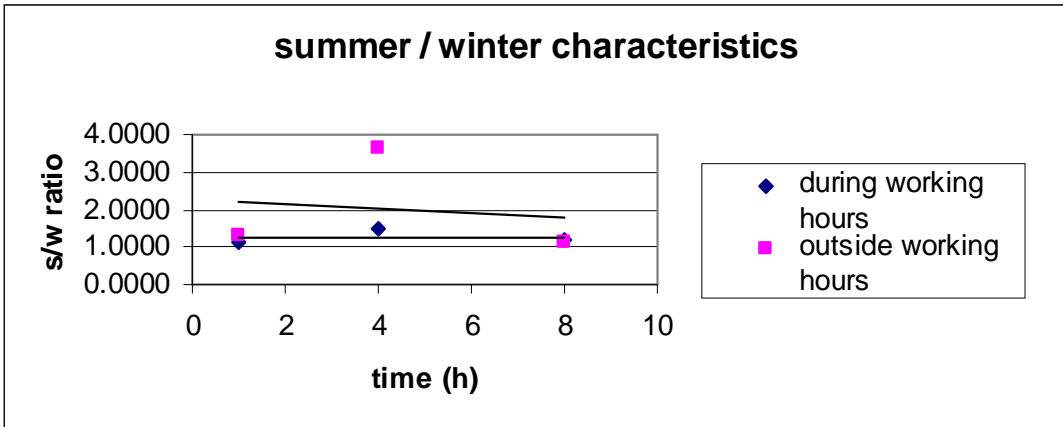


FIGURE 28: CHARACTERISTICS OF SUMMER / WINTER OUTAGE COSTS FOR THE DEPARTMENT STORE SECTOR

s/w ratio during working hours: $y = 0.0036x + 1.2431 \quad R^2 = 0.0036$

s/w ratio outside working hours: $y = -0.0606x + 2.2974 \quad R^2 = 0.0233$

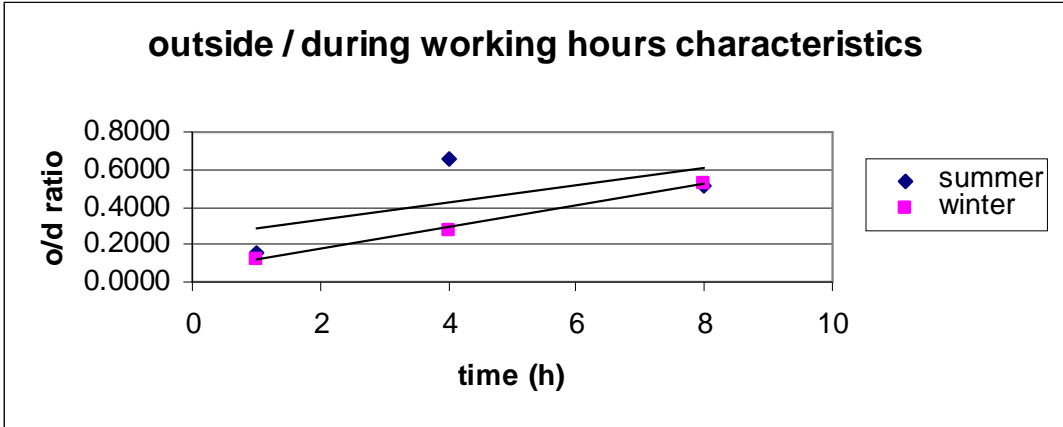


FIGURE 29: CHARACTERISTICS OF OUTSIDE / DURING WORKING HOURS OUTAGE COSTS FOR THE DEPARTMENT STORE SECTOR

o/d ratio in the summer: $y = 0.0468x + 0.2384 \quad R^2 = 0.3906$

o/d ratio in the winter: $y = 0.0578x + 0.0578 \quad R^2 = 0.9949$

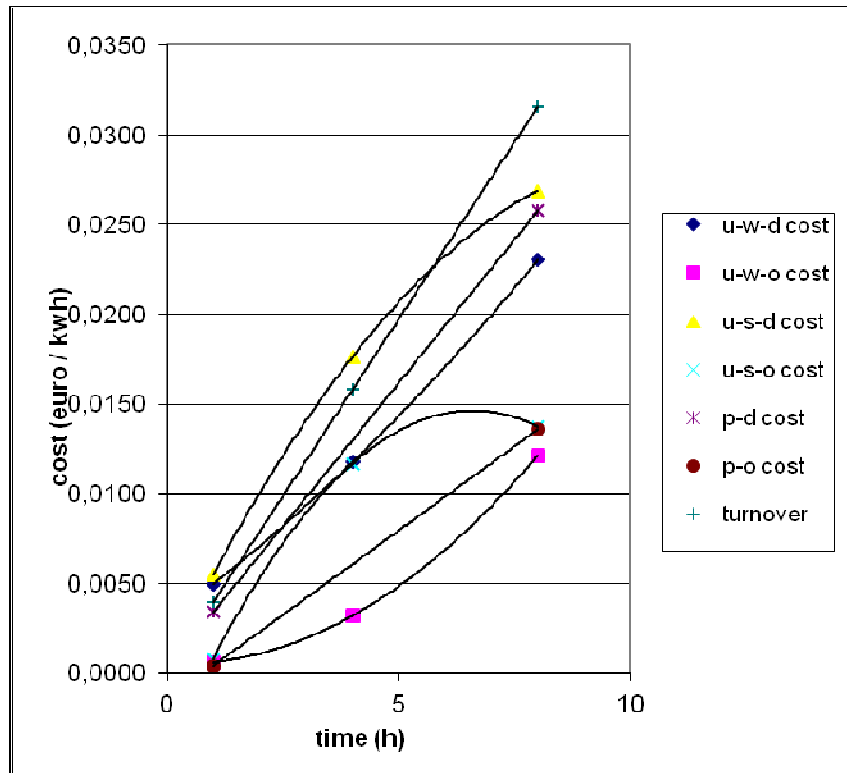


FIGURE 30: SUMMARY OF OUTAGE COST CHARACTERISTICS FOR THE DEPARTMENT STORE SECTOR

5.1.3 OTHER RETAIL

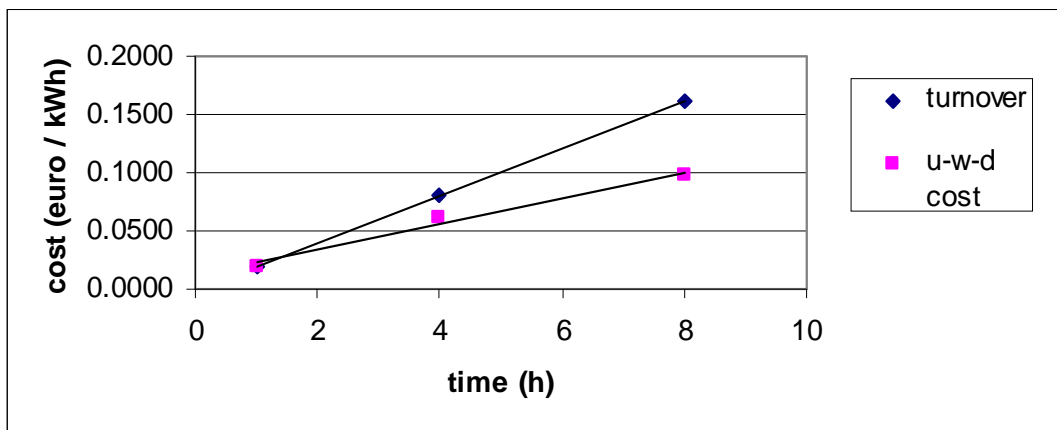


FIGURE 31: TURNOVER AND U-W-D OUTAGE COST ANALYSIS RESULTS FOR THE OTHER RETAIL SECTOR

Linear regression results:

Turnover: $y = 0.0201x$ $R^2 = 1$

Reported u-w-d cost: $y = 0.0111x + 0.0117$ $R^2 = 0.9793$

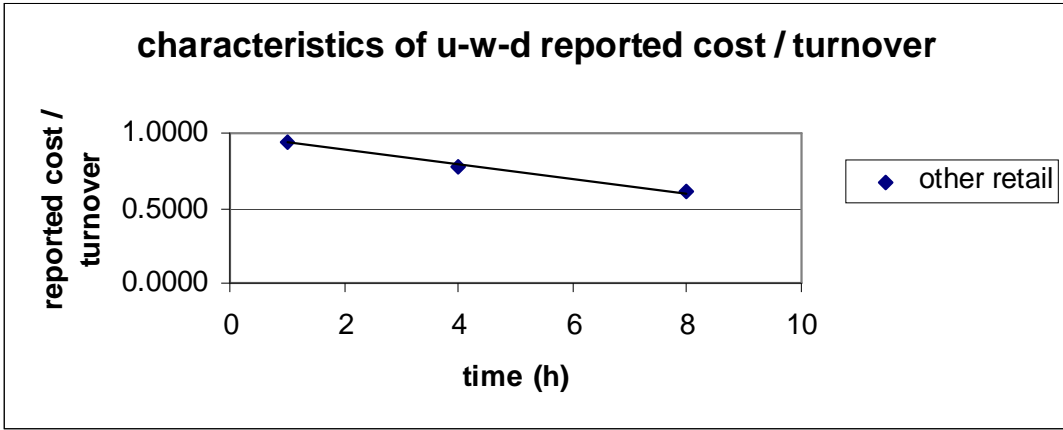


FIGURE 32: CHARACTERISTICS OF U-W-D REPORTED COST / TURNOVER FOR THE OTHER RETAIL SECTOR

u-w-d reported cost / turnover : $y = -0.0484x + 0.9860$ $R^2 = 0.9934$

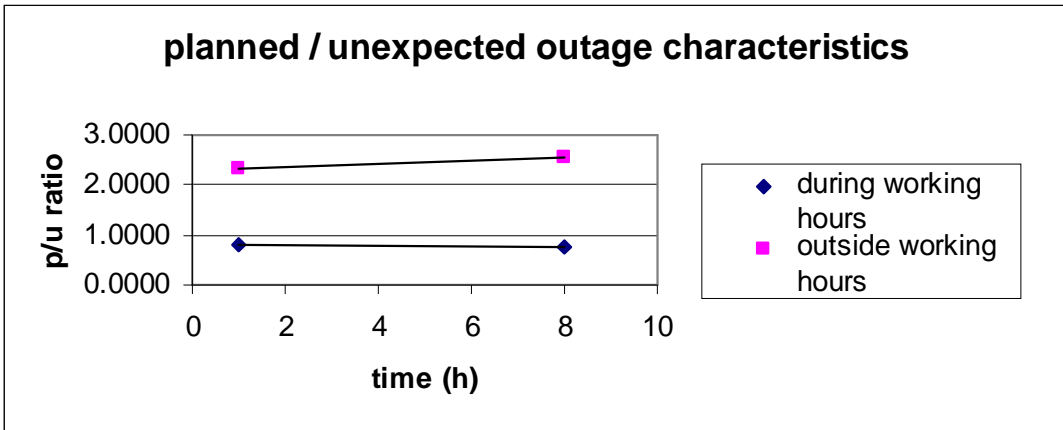


FIGURE 33: CHARACTERISTICS OF PLANNED / UNEXPECTED OUTAGE COSTS FOR THE OTHER RETAIL SECTOR

p/u ratio during working hours: $y = -0.0036x + 0.8032$ $R^2 = 1$

p/u ratio outside working hours: $y = 0.0320x + 2.2834$ $R^2 = 1$

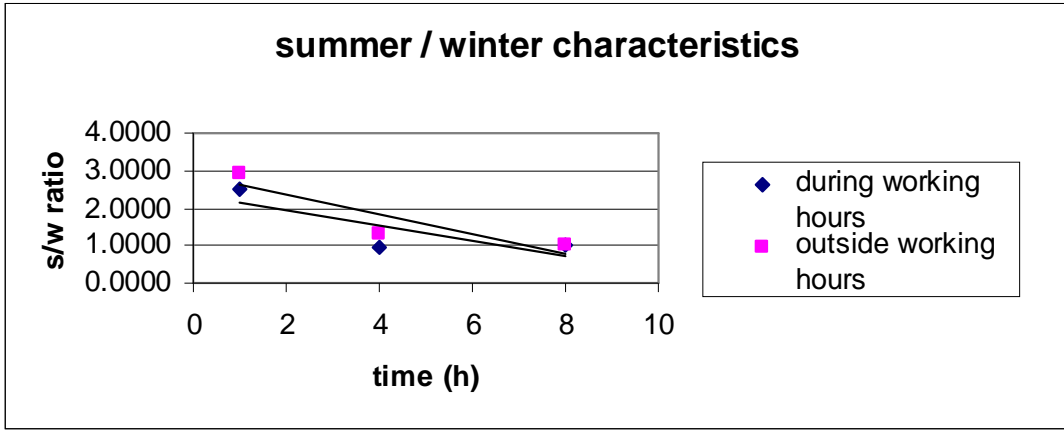


FIGURE 34: CHARACTERISTICS OF SUMMER / WINTER OUTAGE COSTS FOR THE OTHER RETAIL SECTOR

s/w ratio during working hours: $y = -0.2034x + 2.3580$ $R^2 = 0.6433$

s/w ratio outside working hours: $y = -0.2652x + 2.9097$ $R^2 = 0.8163$

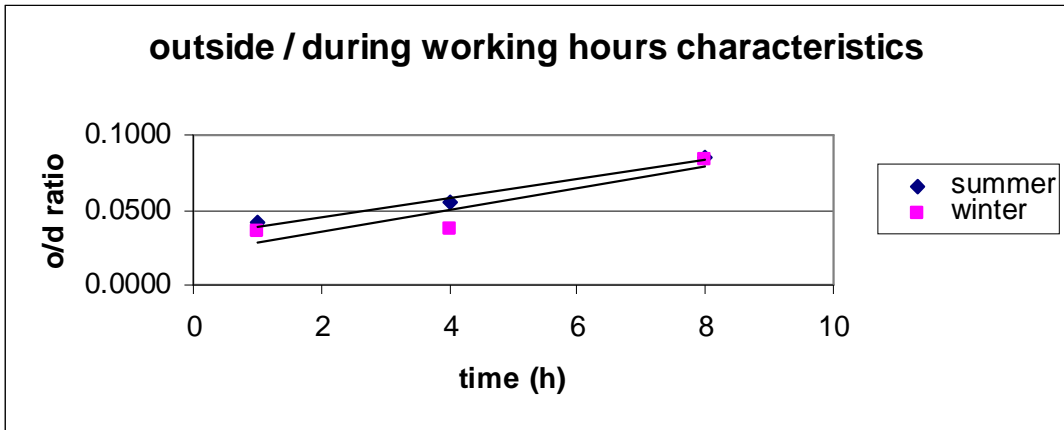


FIGURE 35: CHARACTERISTICS OF OUTSIDE / DURING WORKING HOURS OUTAGE COSTS FOR THE OTHER RETAIL SECTOR

o/d ratio in the summer: $y = 0.0063x + 0.0331$ $R^2 = 0.9804$

o/d ratio in the winter: $y = 0.0072x + 0.0213$ $R^2 = 0.8537$

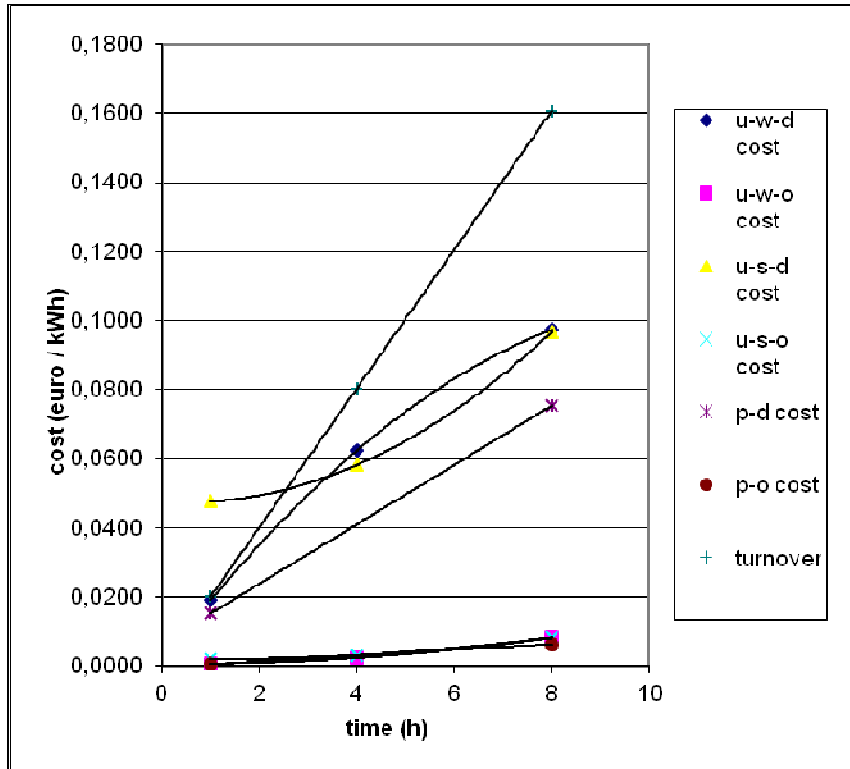


FIGURE 36: SUMMARY OF OUTAGE COST CHARACTERISTICS FOR THE OTHER RETAIL SECTOR

5.1.4 GARAGE

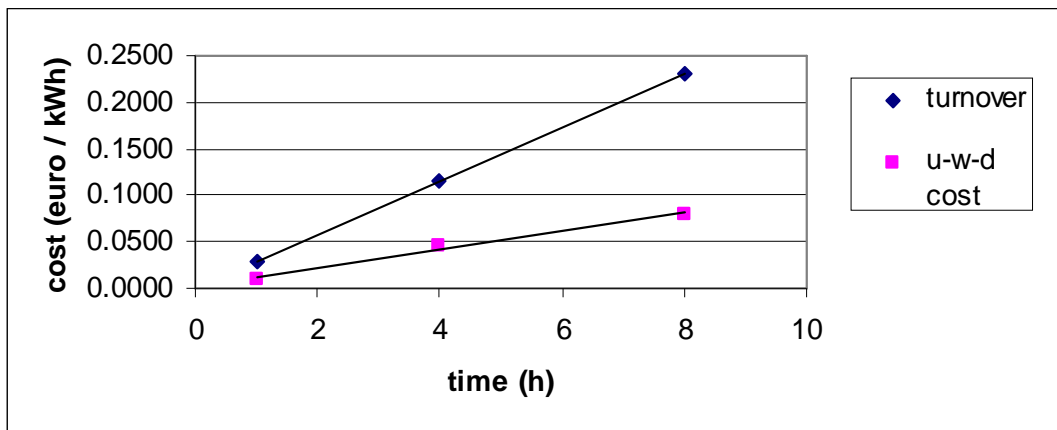


FIGURE 37: TURNOVER AND U-W-D OUTAGE COST ANALYSIS RESULTS FOR THE GARAGE SECTOR

Linear regression results:

Turnover: $y = 0.0289x + 5E-17$ $R^2 = 1$

Reported u-w-d cost: $y = 0.0098x + 0.0028$ $R^2 = 0.9903$

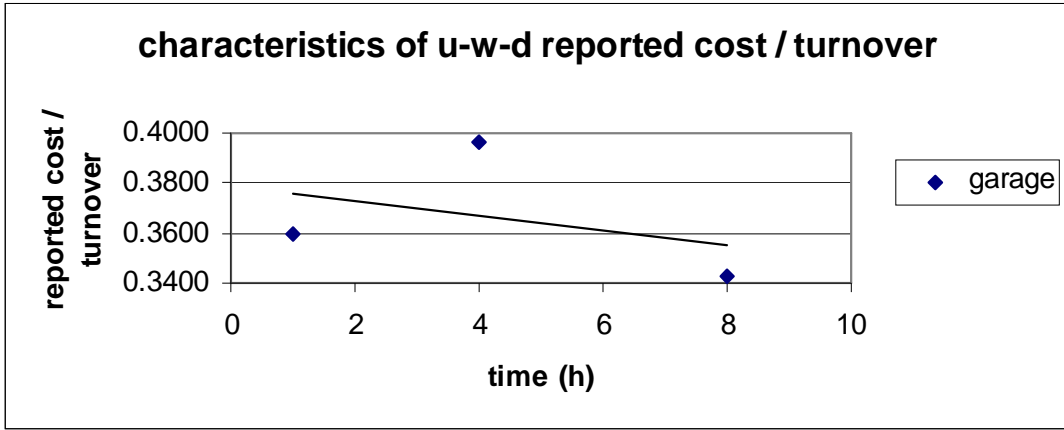


FIGURE 38: CHARACTERISTICS OF U-W-D REPORTED COST / TURNOVER FOR THE GARAGE SECTOR

u-w-d reported cost / turnover : $y = -0.0029x + 0.3789$ $R^2 = 0.1395$

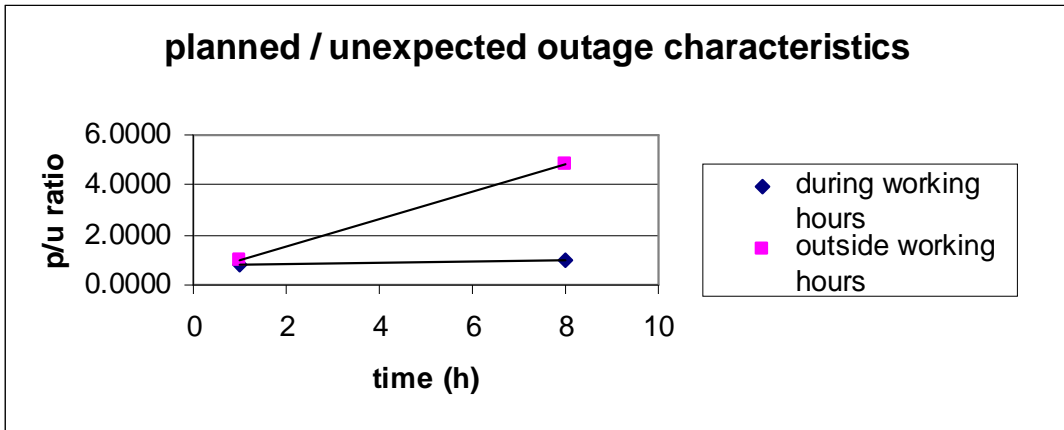


FIGURE 39: CHARACTERISTICS OF PLANNED / UNEXPECTED OUTAGE COSTS FOR THE GARAGE SECTOR

p/u ratio during working hours: $y = 0.0272x + 0.8051$ $R^2 = 1$

p/u ratio outside working hours: $y = 0.5477x + 0.4523$ $R^2 = 1$

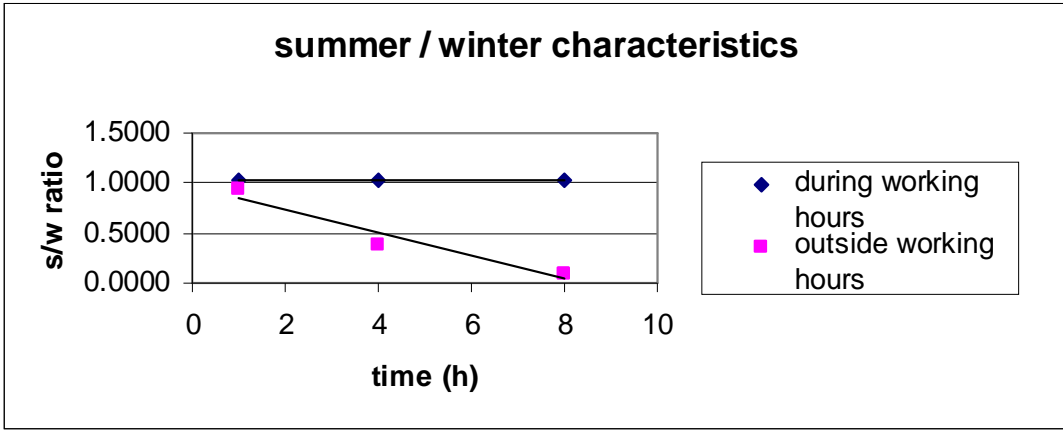


FIGURE 40: CHARACTERISTICS OF SUMMER / WINTER OUTAGE COSTS FOR THE GARAGE SECTOR

s/w ratio during working hours: $y = -0.0019x + 1.0343 \quad R^2 = 0.9983$

s/w ratio outside working hours: $y = -0.1170x + 0.9719 \quad R^2 = 0.9298$

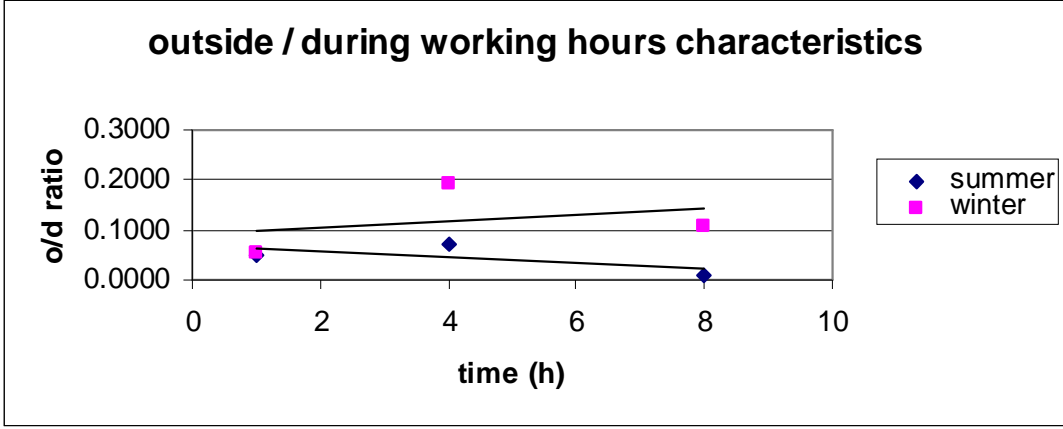


FIGURE 41: CHARACTERISTICS OF OUTSIDE / DURING WORKING HOURS OUTAGE COSTS FOR THE GARAGE SECTOR

o/d ratio in the summer: $y = -0.0060x + 0.0686 \quad R^2 = 0.4832$

o/d ratio in the winter: $y = 0.0065x + 0.0902 \quad R^2 = 0.1076$

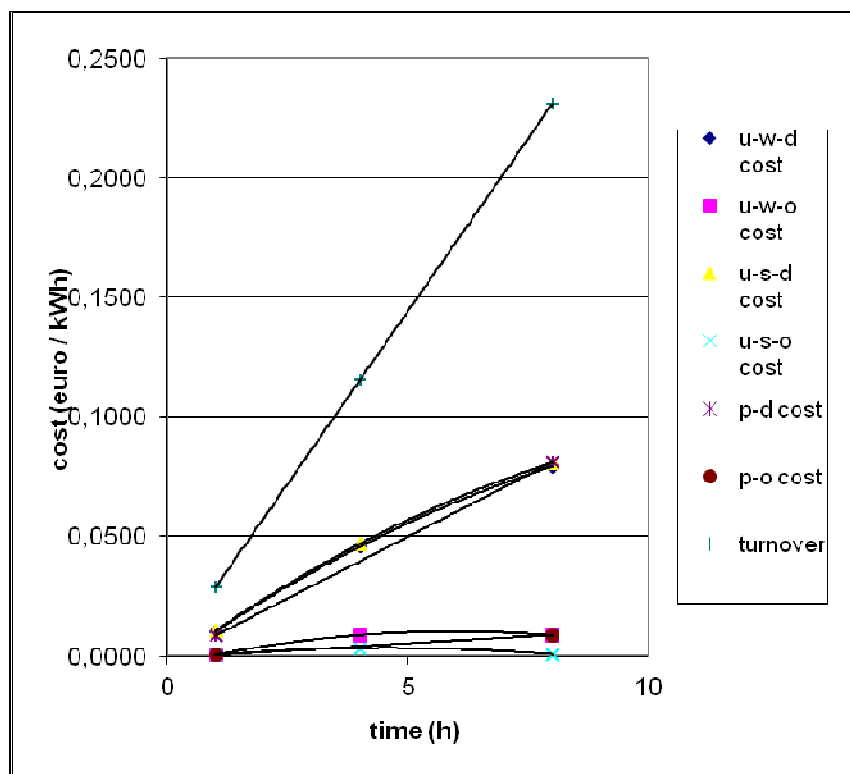


FIGURE 42: SUMMARY OF OUTAGE COST CHARACTERISTICS FOR THE GARAGE SECTOR

5.1.5 HOTEL

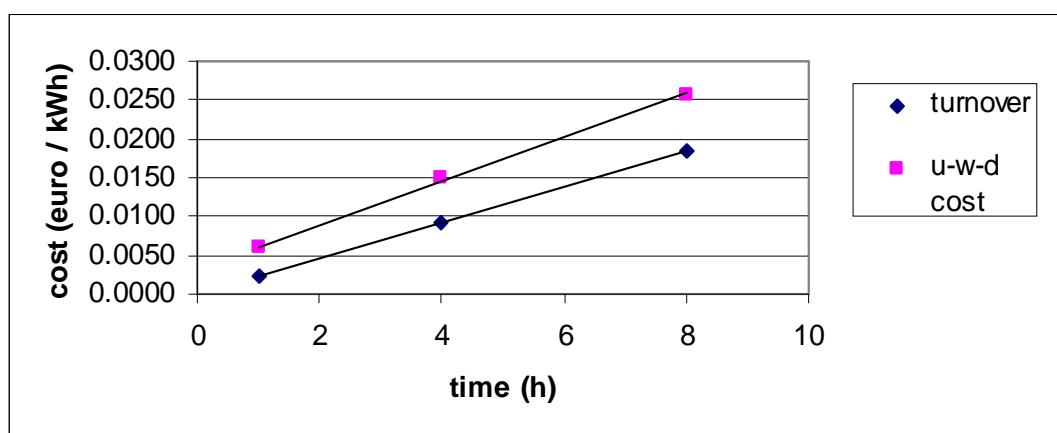


FIGURE 43: TURNOVER AND U-W-D OUTAGE COST ANALYSIS RESULTS FOR THE HOTEL SECTOR

Linear regression results:

Turnover: $y = 0.0023x$ $R^2 = 1$

Reported u-w-d cost: $y = 0.0028x + 0.0033$ $R^2 = 0.9993$

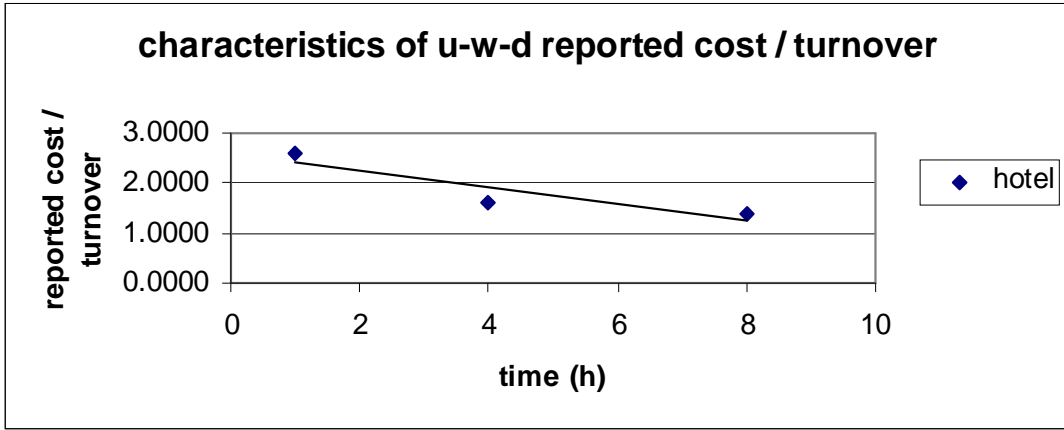


FIGURE 44: CHARACTERISTICS OF U-W-D REPORTED COST / TURNOVER FOR THE HOTEL SECTOR

u-w-d reported cost / turnover : $y = -0.1636x + 2.5813$ $R^2 = 0.8259$

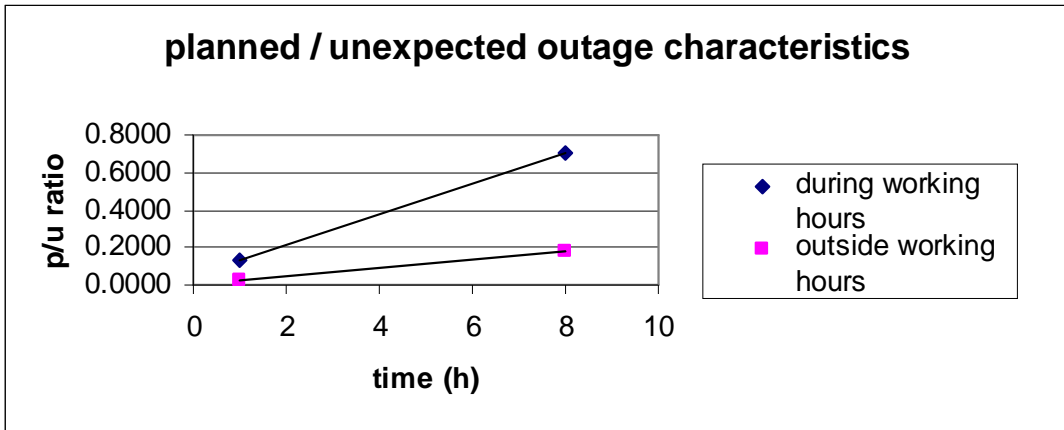


FIGURE 45: CHARACTERISTICS OF PLANNED / UNEXPECTED OUTAGE COSTS FOR THE HOTEL SECTOR

p/u ratio during working hours: $y = 0.0817x + 0.0513$ $R^2 = 1$

p/u ratio outside working hours: $y = 0.0219x + 0.0008$ $R^2 = 1$

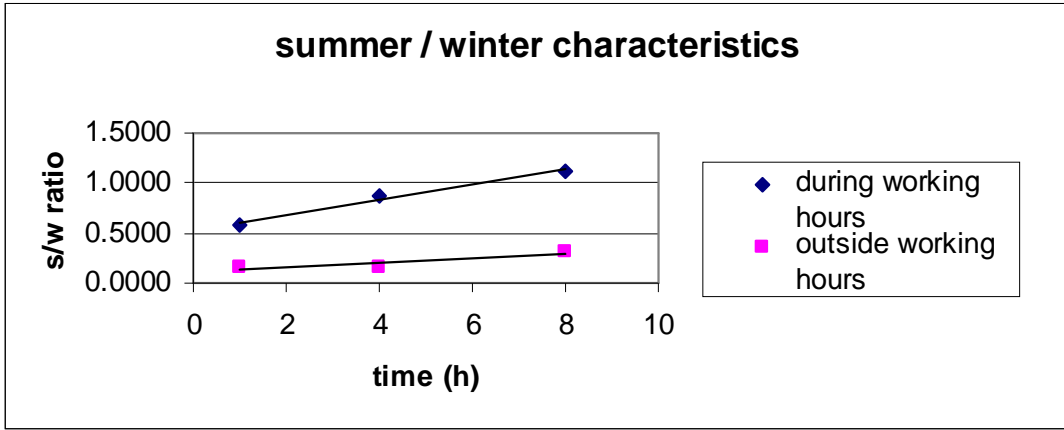


FIGURE 46: CHARACTERISTICS OF SUMMER / WINTER OUTAGE COSTS FOR THE HOTEL SECTOR

s/w ratio during working hours: $y = 0.0777x + 0.5165$ $R^2 = 0.9855$

s/w ratio outside working hours: $y = 0.0227x + 0.1054$ $R^2 = 0.0811$

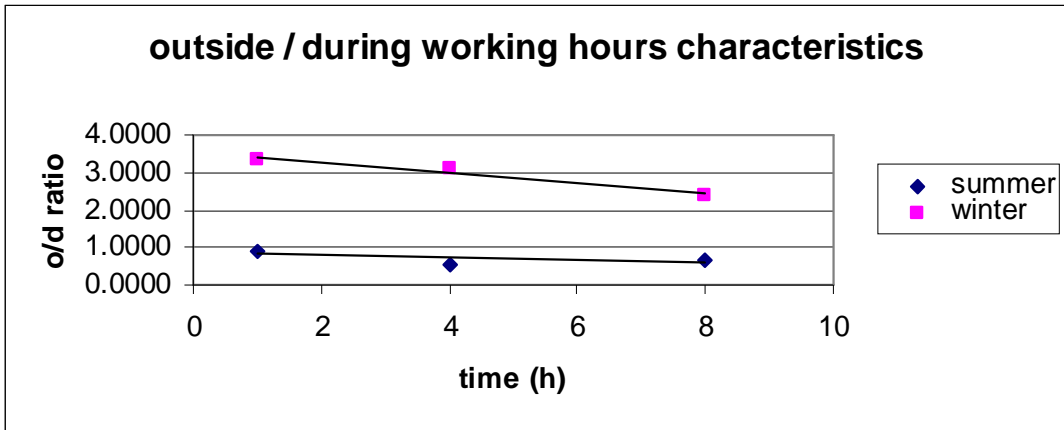


FIGURE 47: CHARACTERISTICS OF OUTSIDE / DURING WORKING HOURS OUTAGE COSTS FOR THE HOTEL SECTOR

o/d ratio in the summer: $y = -0.0321x + 0.8395$ $R^2 = 0.3531$

o/d ratio in the winter: $y = -0.1391x + 3.5550$ $R^2 = 0.9787$

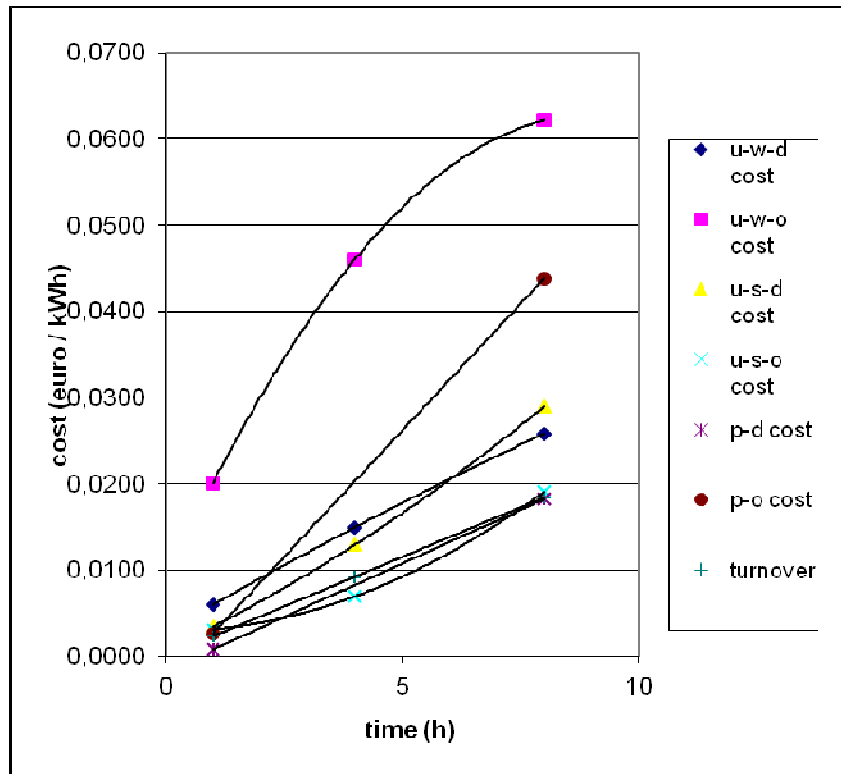


FIGURE 48: SUMMARY OF OUTAGE COST CHARACTERISTICS FOR THE HOTEL SECTOR

5.1.6 RESTAURANT

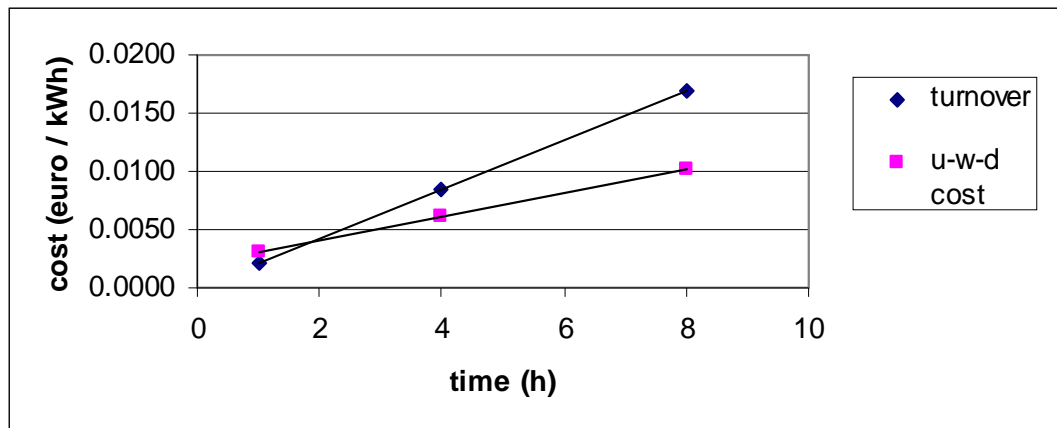


FIGURE 49: TURNOVER AND U-W-D OUTAGE COST ANALYSIS RESULTS FOR THE RESTAURANT SECTOR

Linear regression results:

Turnover: $y = 0.0021x$ $R^2 = 1$

Reported u-w-d cost: $y = 0.0010x + 0.0021$ $R^2 = 0.9997$

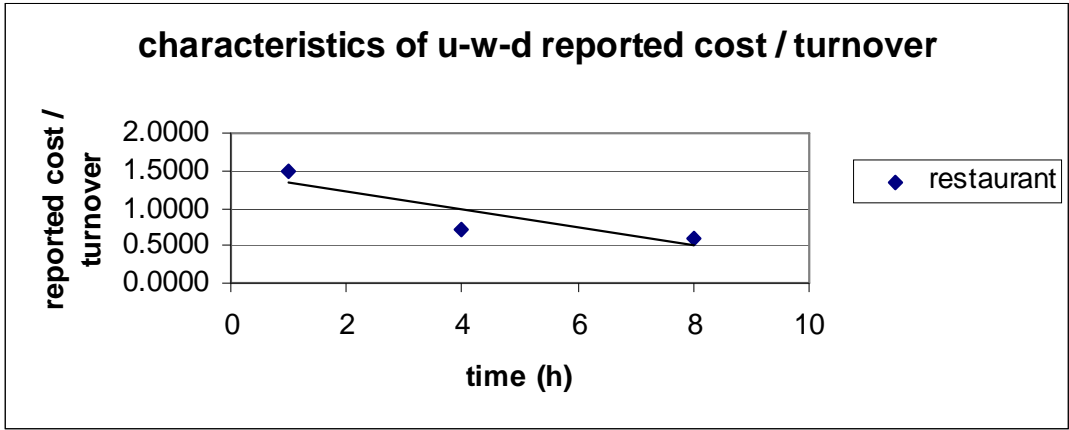


FIGURE 50: CHARACTERISTICS OF U-W-D REPORTED COST / TURNOVER FOR THE RESTAURANT SECTOR

u-w-d reported cost / turnover : $y = -0.1207x + 1.4624$ $R^2 = 0.7810$

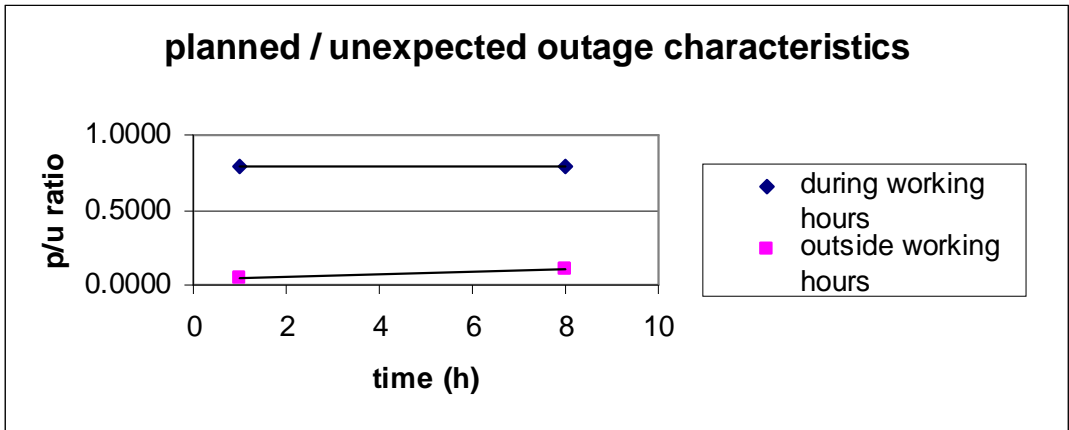


FIGURE 51: CHARACTERISTICS OF PLANNED / UNEXPECTED OUTAGE COSTS FOR THE RESTAURANT SECTOR

p/u ratio during working hours: $y = -0.0013x + 0.7997$ $R^2 = 1$

p/u ratio outside working hours: $y = 0.0085x + 0.0305$ $R^2 = 1$

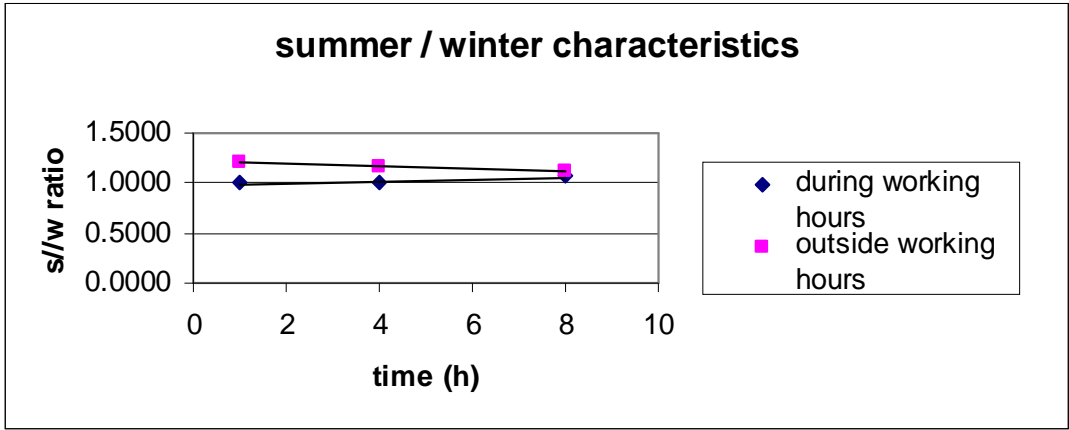


FIGURE 52: CHARACTERISTICS OF SUMMER / WINTER OUTAGE COSTS FOR THE RESTAURANT SECTOR

s/w ratio during working hours: $y = 0.0100x + 0.9824$ $R^2 = 0.7985$

s/w ratio outside working hours: $y = -0.0150x + 1.2320$ $R^2 = 0.9998$

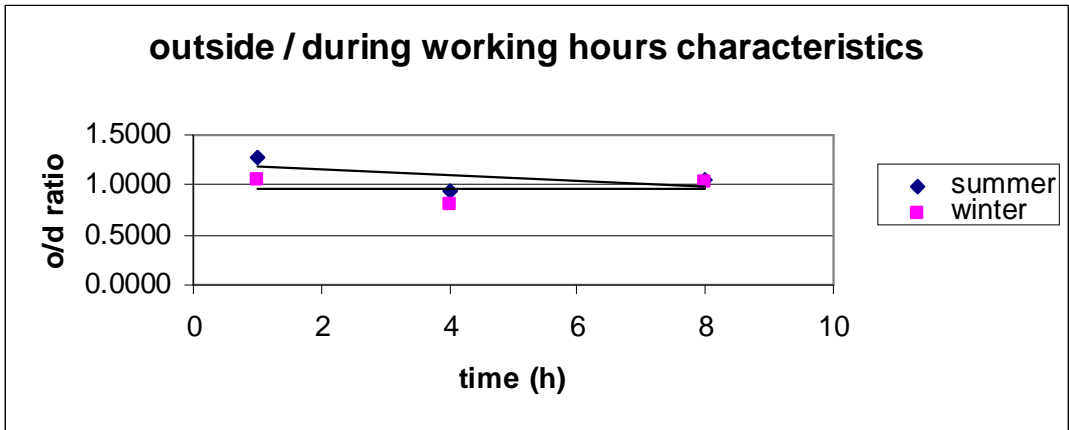


FIGURE 53: CHARACTERISTICS OF OUTSIDE / DURING WORKING HOURS OUTAGE COSTS FOR THE RESTAURANT SECTOR

o/d ratio in the summer: $y = -0.0260x + 1.2041$ $R^2 = 0.3197$

o/d ratio in the winter: $y = -6E-05x + 0.9589$ $R^2 = 2E-06$

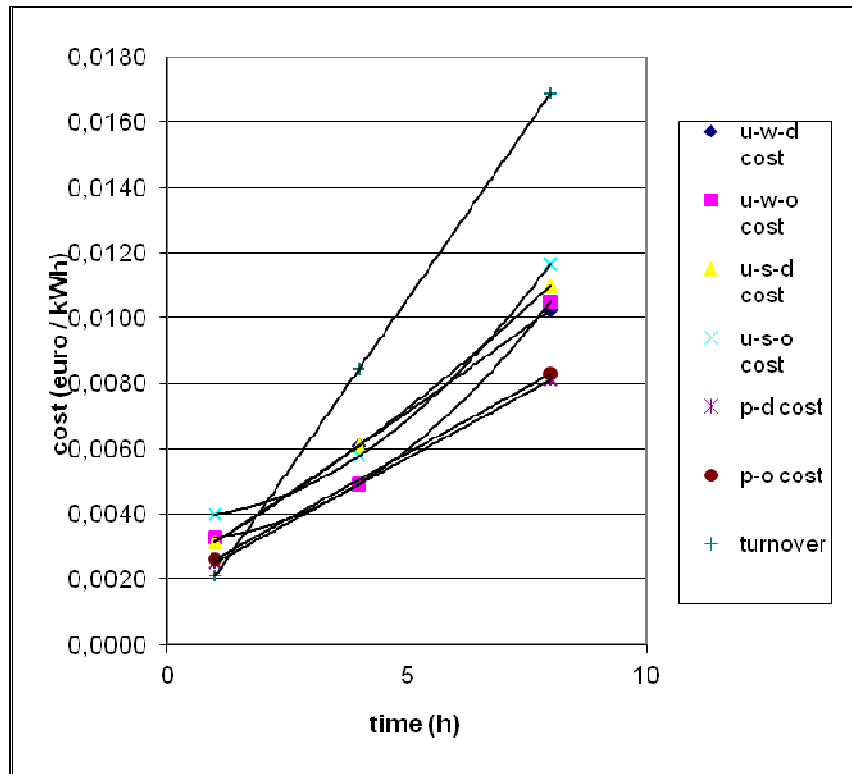


FIGURE 54: SUMMARY OF OUTAGE COST CHARACTERISTICS FOR THE RESTAURANT SECTOR

5.1.7 FINANCE

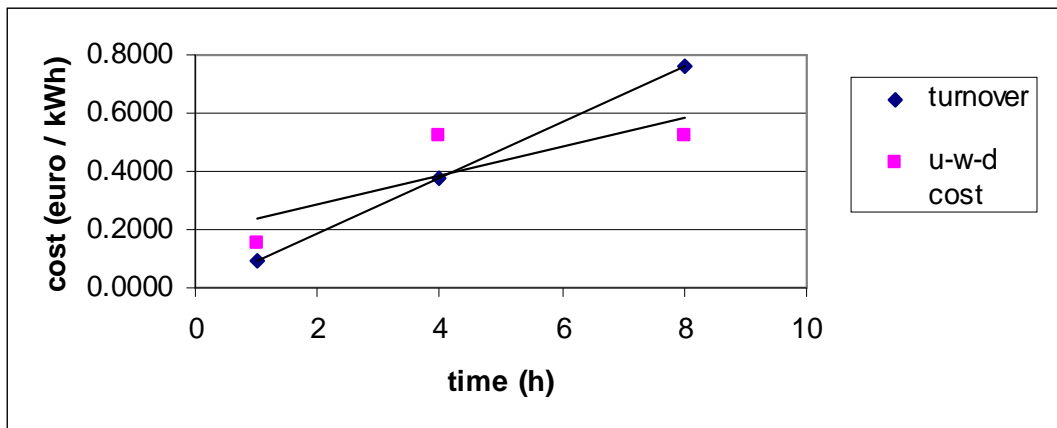


FIGURE 55: TURNOVER AND U-W-D OUTAGE COST ANALYSIS RESULTS FOR THE FINANCE SECTOR

Linear regression results:

Turnover: $y = 0.0949x$ $R^2 = 1$

Reported u-w-d cost: $y = 0.0495x + 0.1868$ $R^2 = 0.6757$

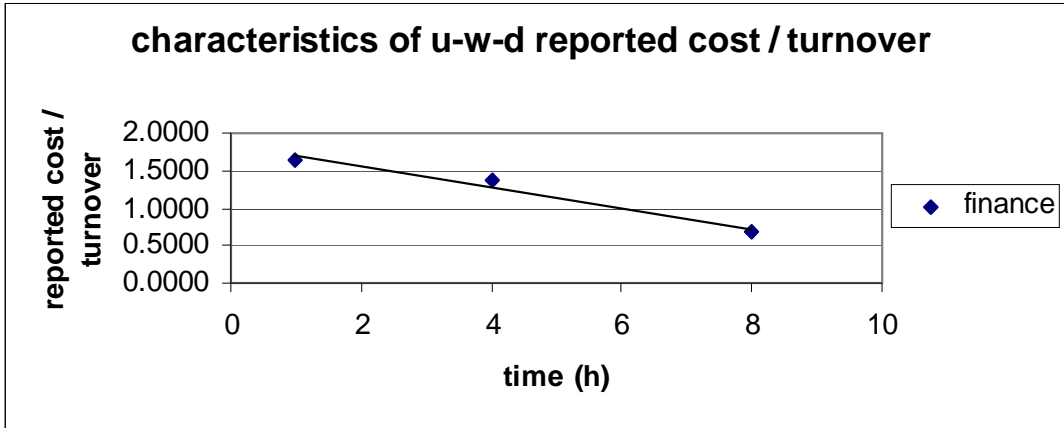


FIGURE 56: CHARACTERISTICS OF U-W-D REPORTED COST / TURNOVER FOR THE FINANCE SECTOR

u-w-d reported cost / turnover : $y = -0.1397x + 1.8465 \quad R^2 = 0.9743$

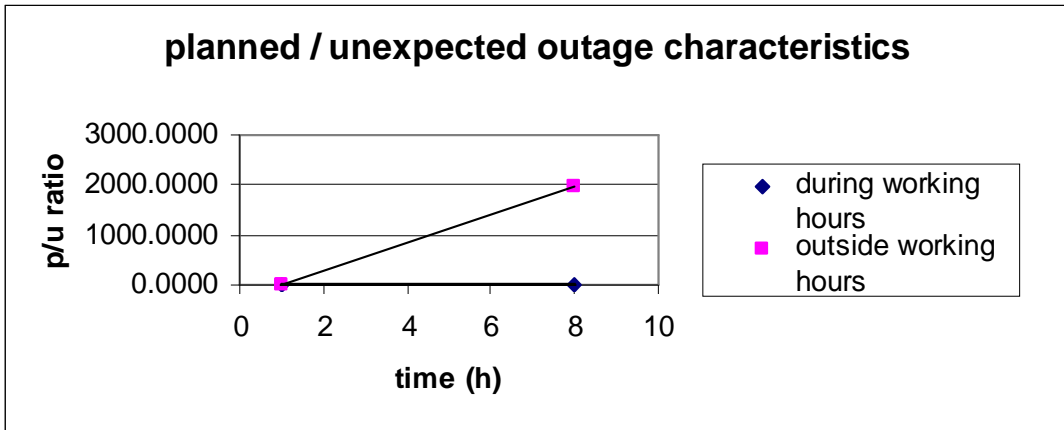


FIGURE 57: CHARACTERISTICS OF PLANNED / UNEXPECTED OUTAGE COSTS FOR THE FINANCE SECTOR

p/u ratio during working hours: $y = 0.0833x + 0.5833 \quad R^2 = 1$

p/u ratio outside working hours: $y = 280.41x - 279.41 \quad R^2 = 1$

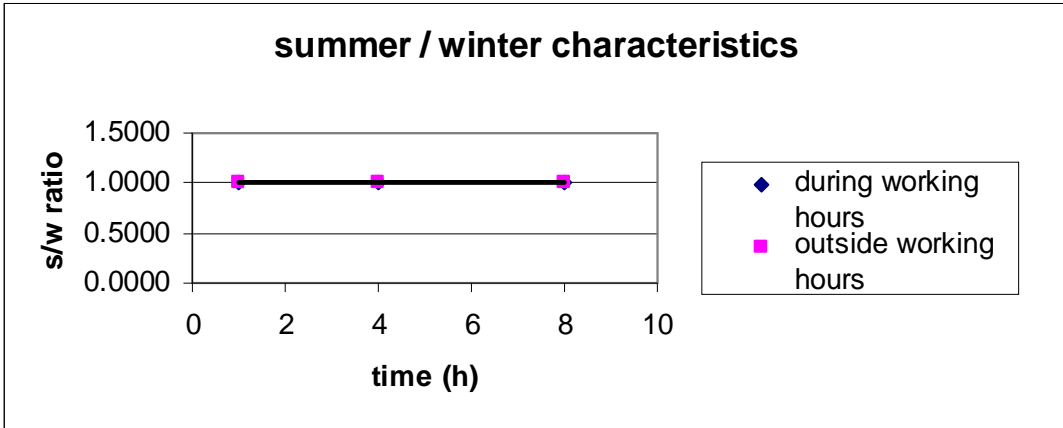


FIGURE 58: CHARACTERISTICS OF SUMMER / WINTER OUTAGE COSTS FOR THE FINANCE SECTOR

s/w ratio during working hours: $y = 1$ $R^2 = 1$

s/w ratio outside working hours: $y = 1$ $R^2 = 1$

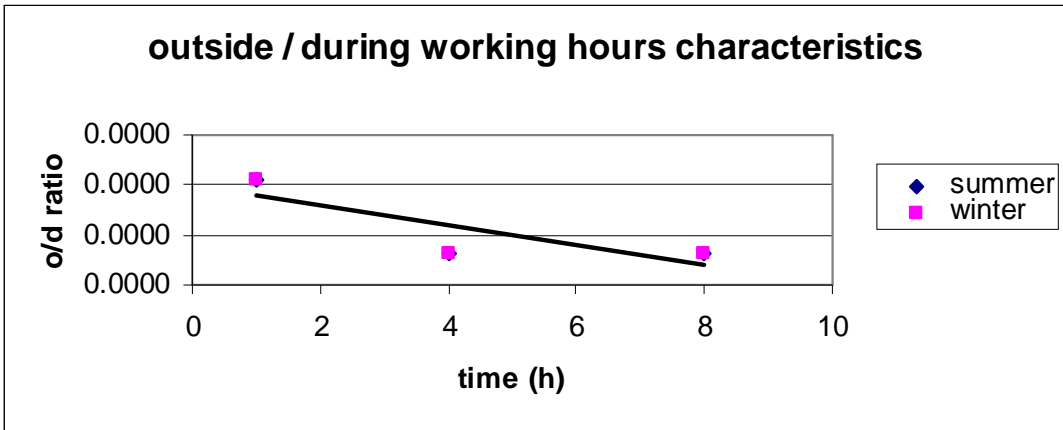


FIGURE 59: CHARACTERISTICS OF OUTSIDE / DURING WORKING HOURS OUTAGE COSTS FOR THE FINANCE SECTOR

o/d ratio in the summer: $y = -2E-06x + 2E-05$ $R^2 = 0.6757$

o/d ratio in the winter: $y = -2E-06x + 2E-05$ $R^2 = 0.6757$

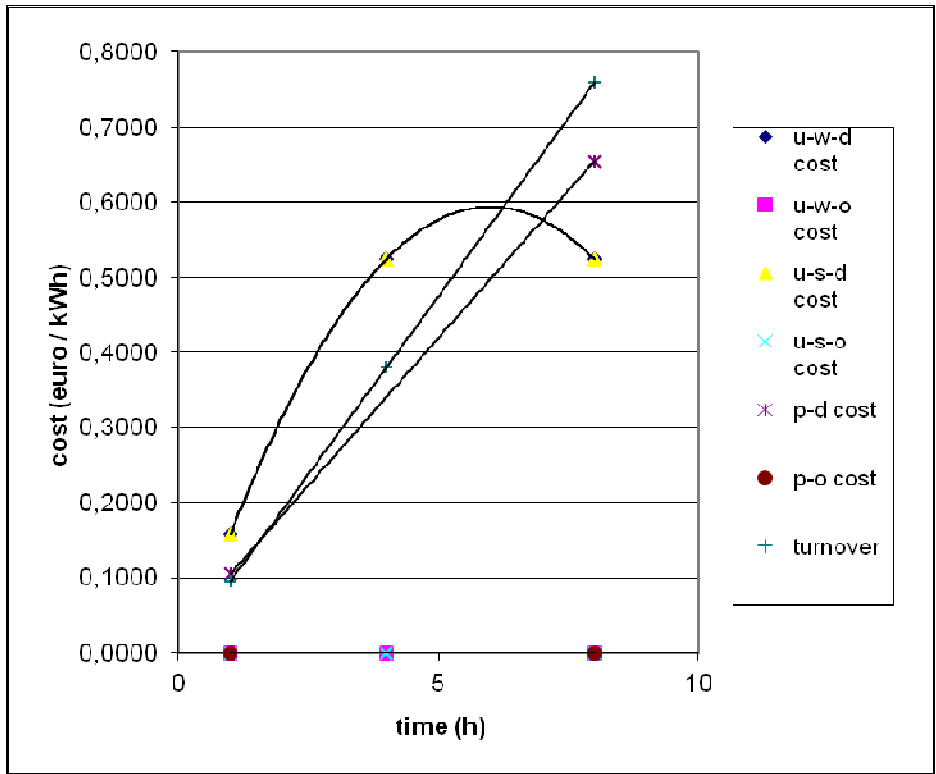


FIGURE 60: SUMMARY OF OUTAGE COST CHARACTERISTICS FOR THE FINANCE SECTOR

* Since the number of respondents of the Finance sector in the survey is insufficient, the results presented for this service sector are not reliable!

5.1.8 SPORTS

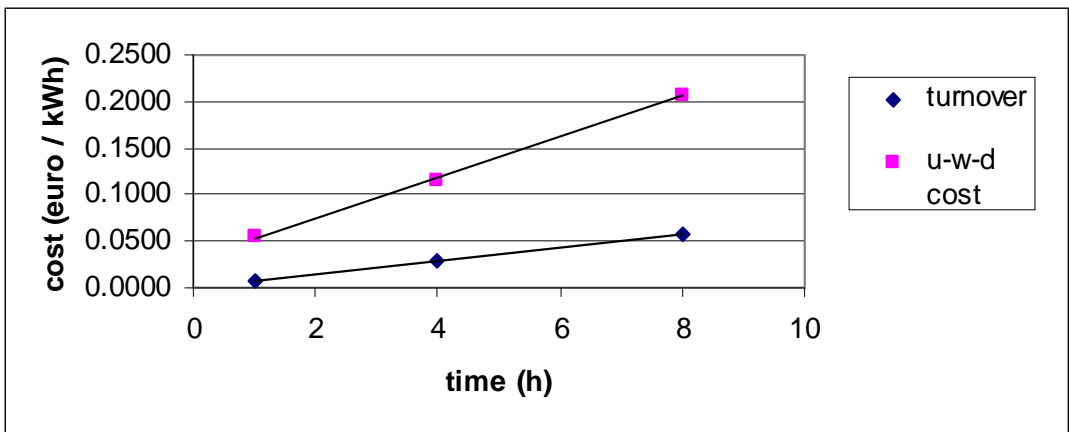


FIGURE 61: TURNOVER AND U-W-D OUTAGE COST ANALYSIS RESULTS FOR THE SPORTS SECTOR

Linear regression results:

Turnover: $y = 0.0072x$ $R^2 = 1$

Reported u-w-d cost: $y = 0.0218x + 0.0318$ $R^2 = 0.9984$

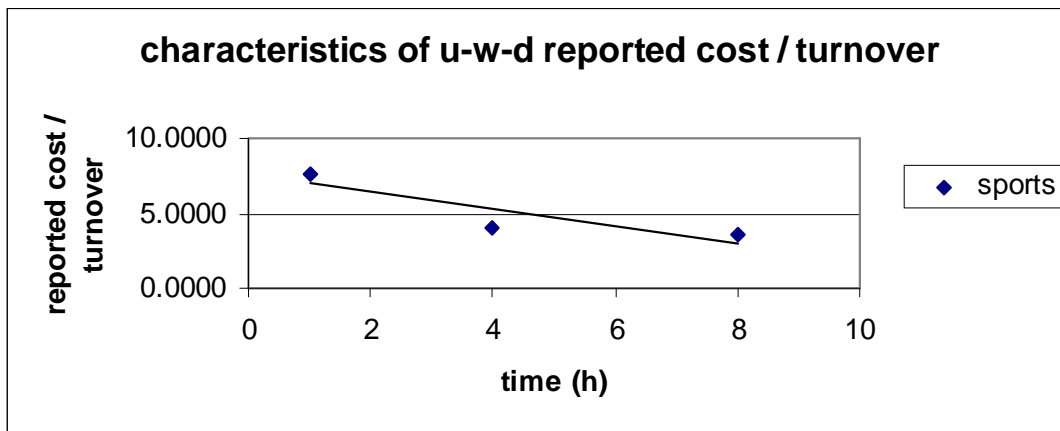


FIGURE 62: CHARACTERISTICS OF U-W-D REPORTED COST / TURNOVER FOR THE SPORTS SECTOR

u-w-d reported cost / turnover : $y = -0.5587x + 7.5042$ $R^2 = 0.7558$

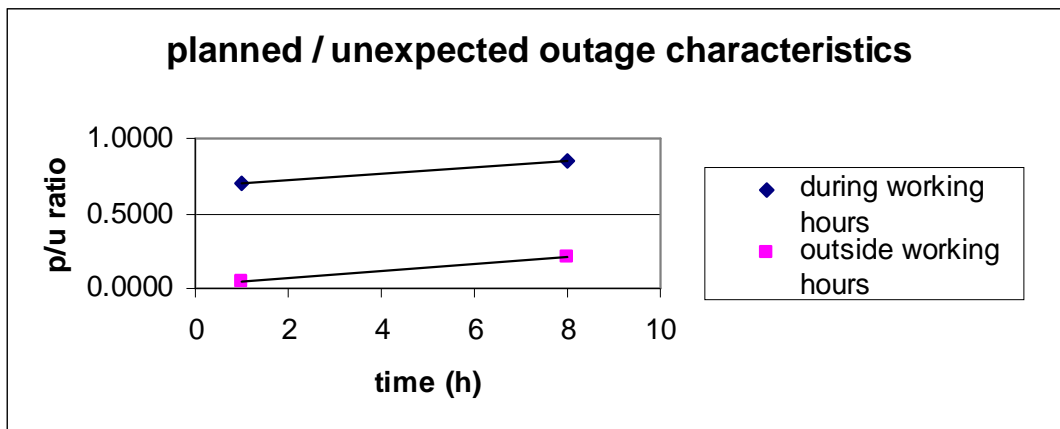


FIGURE 63: CHARACTERISTICS OF PLANNED / UNEXPECTED OUTAGE COSTS FOR THE SPORTS SECTOR

p/u ratio during working hours: $y = 0.0221x + 0.6777$ $R^2 = 1$

p/u ratio outside working hours: $y = 0.0253x + 0.0142$ $R^2 = 1$

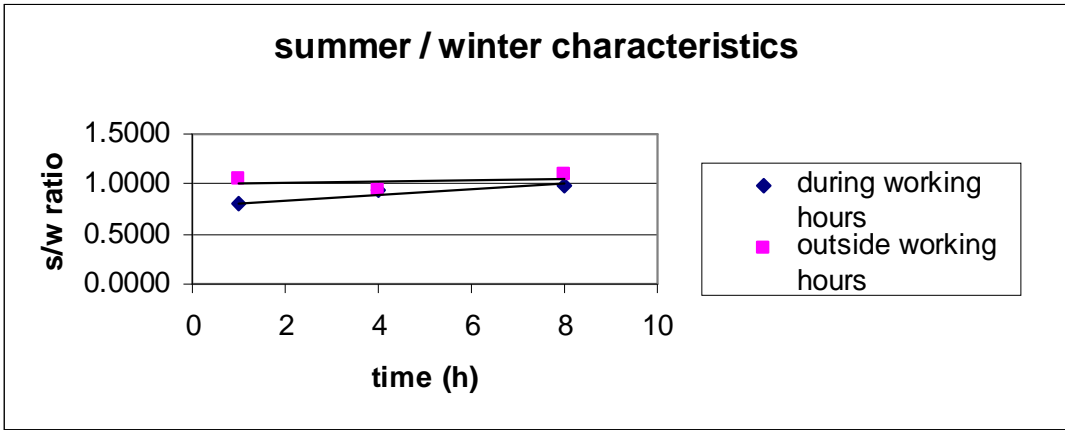


FIGURE 64: CHARACTERISTICS OF SUMMER / WINTER OUTAGE COSTS FOR THE SPORTS SECTOR

s/w ratio during working hours: $y = 0.0264x + 0.7901$ $R^2 = 0.8972$

s/w ratio outside working hours: $y = 0.0084x + 0.9904$ $R^2 = 0.1307$

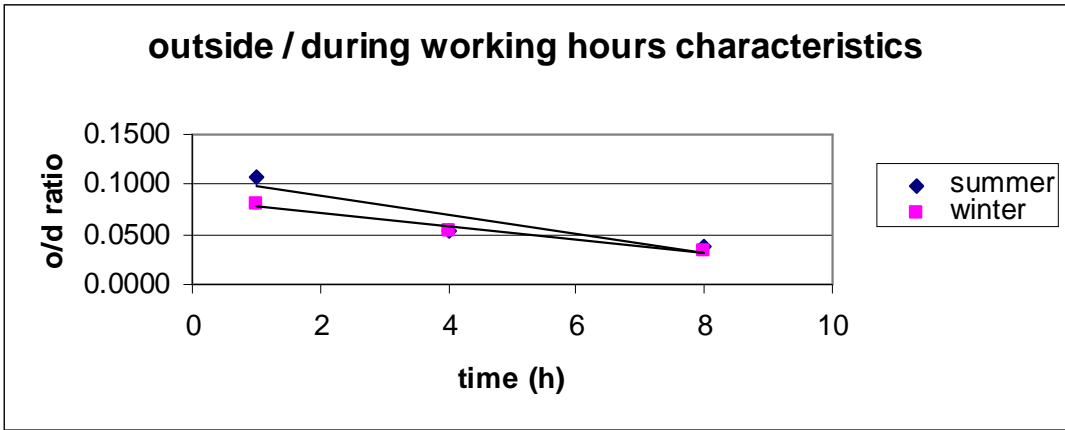


FIGURE 65: CHARACTERISTICS OF OUTSIDE / DURING WORKING HOURS OUTAGE COSTS FOR THE SPORTS SECTOR

o/d ratio in the summer: $y = -0.0096x + 0.1076$ $R^2 = 0.8629$

o/d ratio in the winter: $y = -0.0067x + 0.0850$ $R^2 = 0.9687$

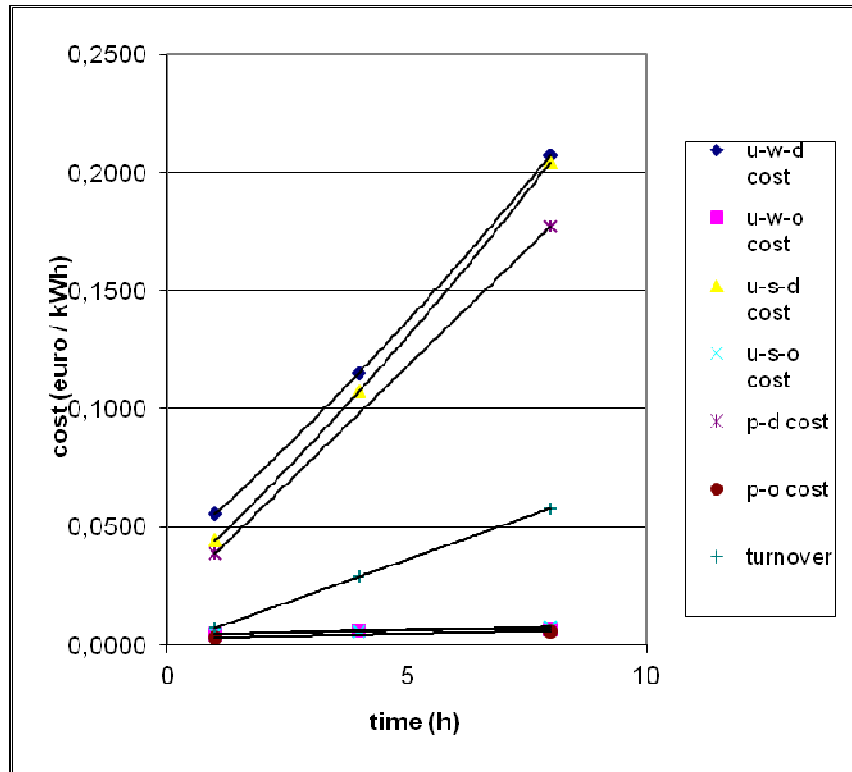


FIGURE 66: SUMMARY OF OUTAGE COST CHARACTERISTICS FOR THE SPORTS SECTOR

5.1.9 IT

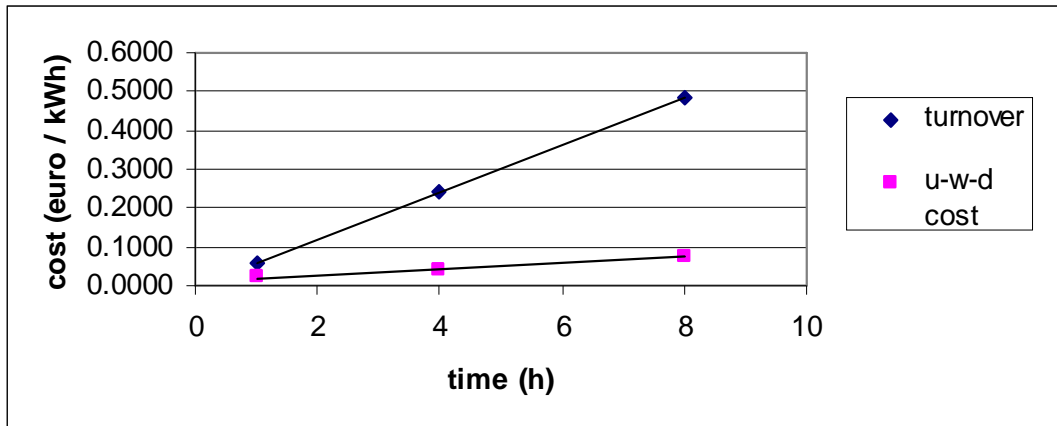


FIGURE 67: TURNOVER AND U-W-D OUTAGE COST ANALYSIS RESULTS FOR THE IT SECTOR

Linear regression results:

Turnover: $y = 0.0605x - 1E-16$ $R^2 = 1$

Reported u-w-d cost: $y = 0.0076x + 0.0124$ $R^2 = 0.9975$

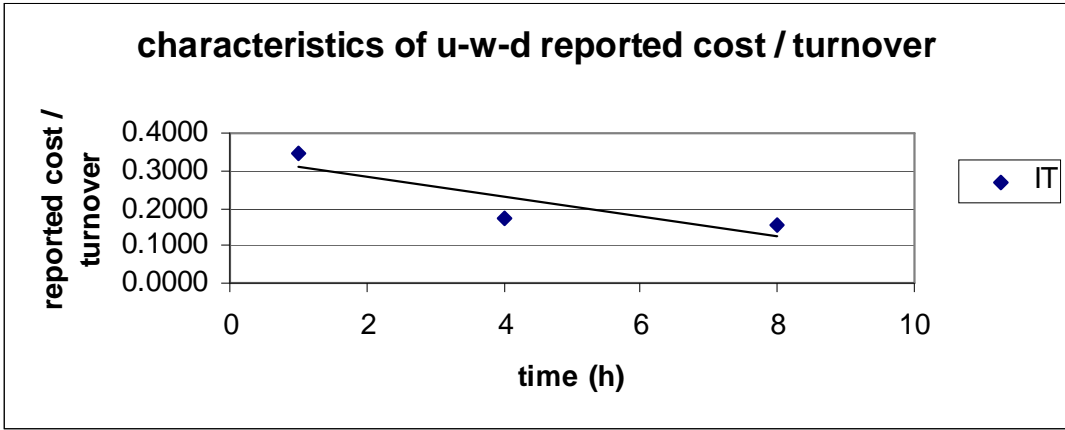


FIGURE 68: CHARACTERISTICS OF U-W-D REPORTED COST / TURNOVER FOR THE IT SECTOR

u-w-d reported cost / turnover : $y = -0.0263x + 0.3370 \quad R^2 = 0.7515$

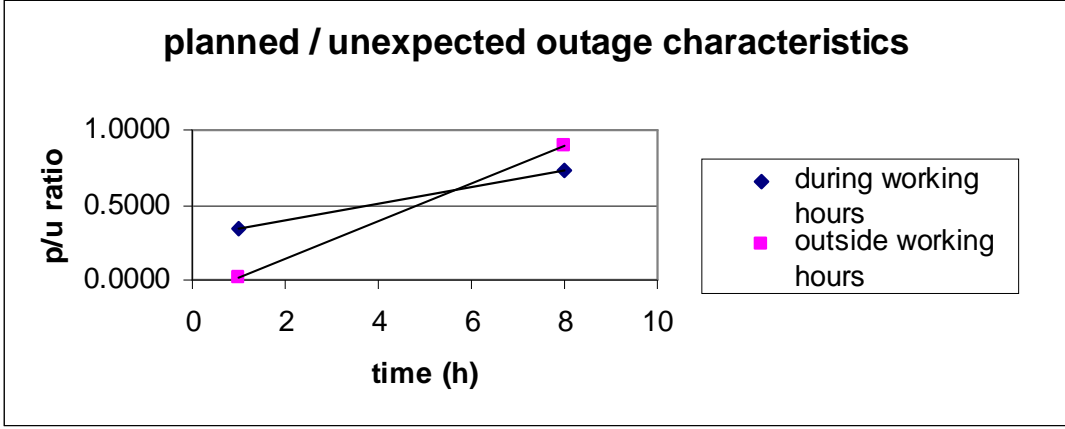


FIGURE 69: CHARACTERISTICS OF PLANNED / UNEXPECTED OUTAGE COSTS FOR THE IT SECTOR

p/u ratio during working hours: $y = 0.0559x + 0.2862 \quad R^2 = 1$

p/u ratio outside working hours: $y = 0.1256x - 0.1152 \quad R^2 = 1$

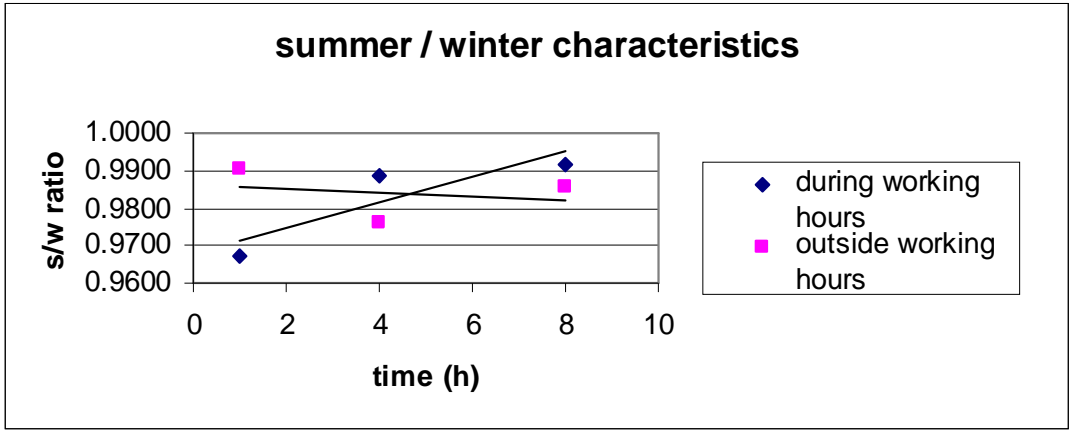


FIGURE 70: CHARACTERISTICS OF SUMMER / WINTER OUTAGE COSTS FOR THE IT SECTOR

s/w ratio during working hours: $y = 0.0034x + 0.9679 \quad R^2 = 0.7734$

s/w ratio outside working hours: $y = -0.0005x + 0.9862 \quad R^2 = 0.0640$

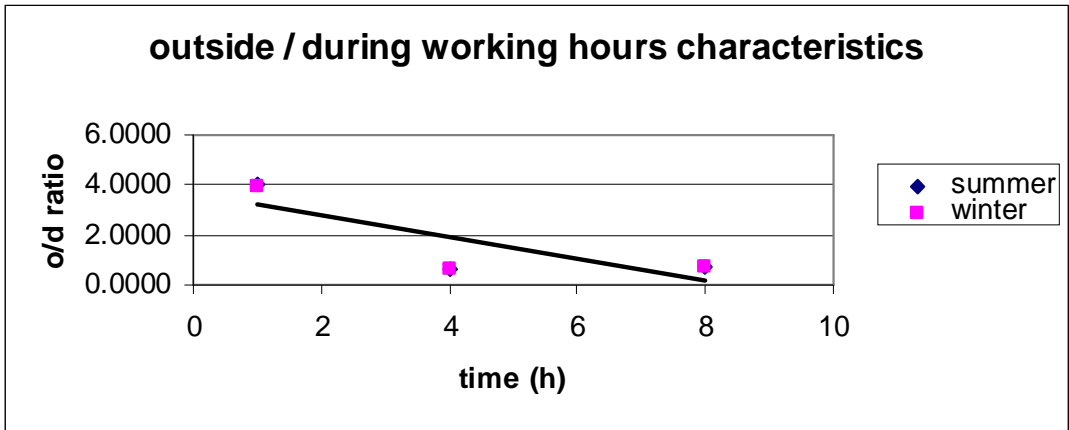


FIGURE 71: CHARACTERISTICS OF OUTSIDE / DURING WORKING HOURS OUTAGE COSTS FOR THE IT SECTOR

o/d ratio in the summer: $y = -0.4384x + 3.6965 \quad R^2 = 0.6524$

o/d ratio in the winter: $y = -0.4252x + 3.6125 \quad R^2 = 0.6525$

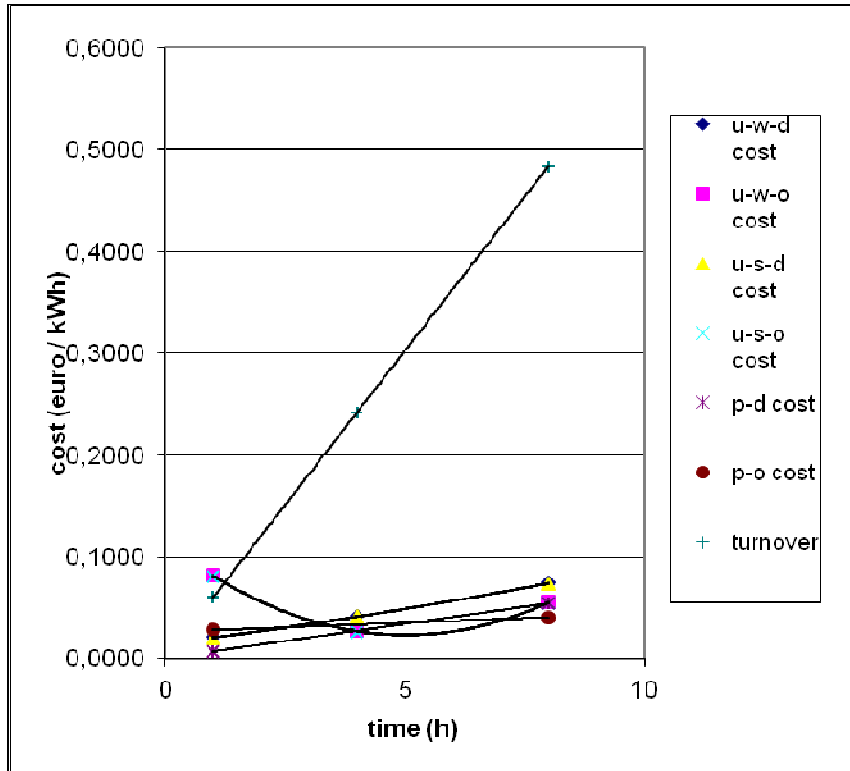


FIGURE 72: SUMMARY OF OUTAGE COST CHARACTERISTICS FOR THE IT SECTOR

5.1.10 HEALTH

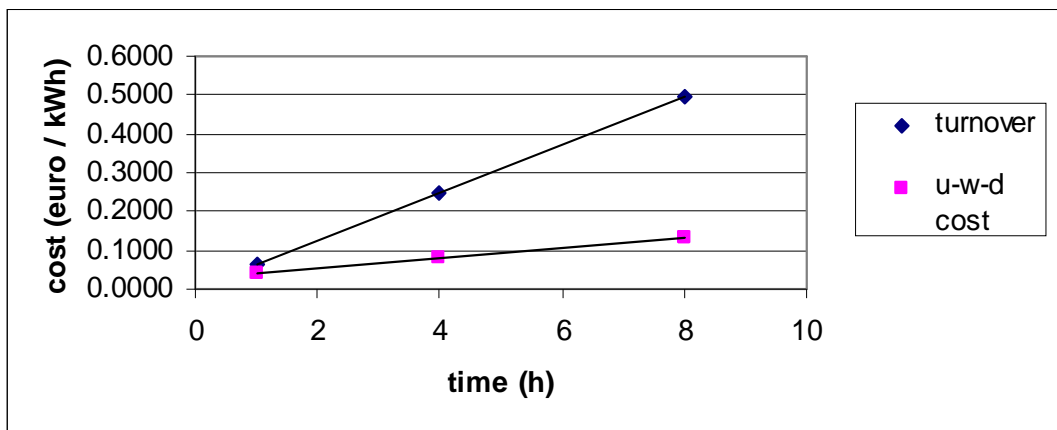


FIGURE 73: TURNOVER AND U-W-D OUTAGE COST ANALYSIS RESULTS FOR THE HEALTH SECTOR

Linear regression results:

Turnover: $y = 0.0623x$ $R^2 = 1$

Reported u-w-d cost: $y = 0.0128x + 0.0289$ $R^2 = 0.9971$

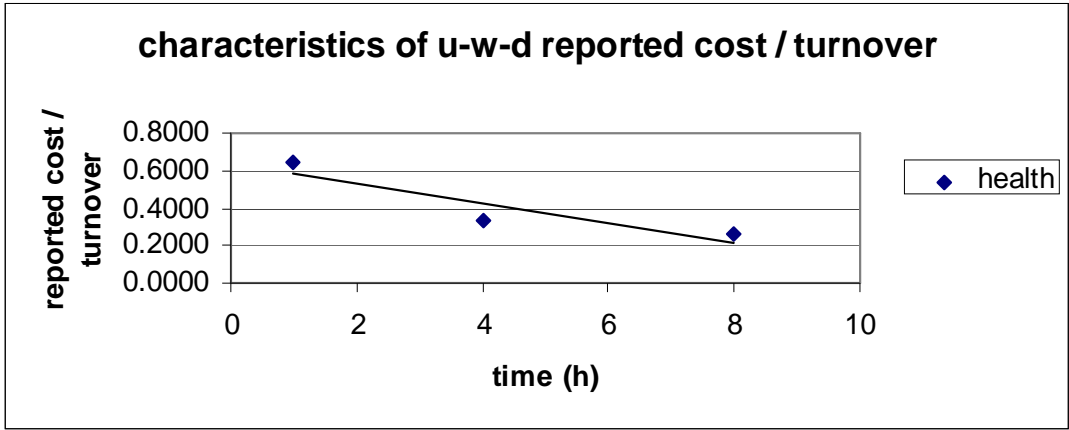


FIGURE 74: CHARACTERISTICS OF U-W-D REPORTED COST / TURNOVER FOR THE HEALTH SECTOR

u-w-d reported cost / turnover : $y = -0.0527x + 0.6404 \quad R^2 = 0.8268$

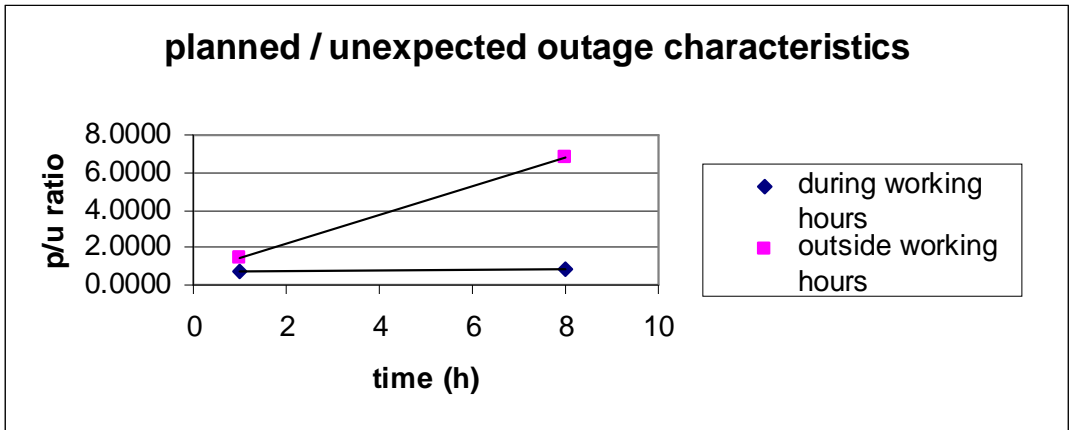


FIGURE 75: CHARACTERISTICS OF PLANNED / UNEXPECTED OUTAGE COSTS FOR THE HEALTH SECTOR

p/u ratio during working hours: $y = 0.0229x + 0.6383 \quad R^2 = 1$

p/u ratio outside working hours: $y = 0.7560x + 0.7298 \quad R^2 = 1$

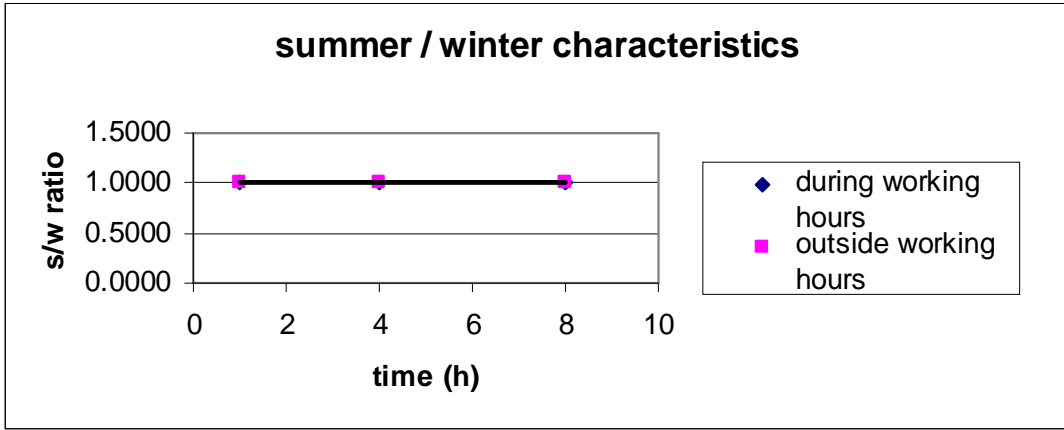


FIGURE 76: CHARACTERISTICS OF SUMMER / WINTER OUTAGE COSTS FOR THE HEALTH SECTOR

s/w ratio during working hours: $y = 1$ $R^2 = 1$

s/w ratio outside working hours: $y = 1$ $R^2 = 1$

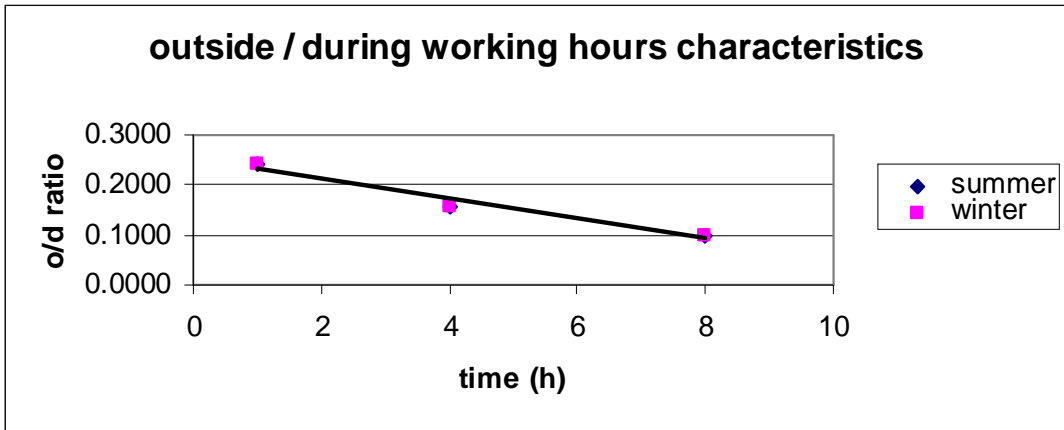


FIGURE 77: CHARACTERISTICS OF OUTSIDE / DURING WORKING HOURS OUTAGE COSTS FOR THE HEALTH SECTOR

o/d ratio in the summer: $y = -0.0201x + 0.2534$ $R^2 = 0.9606$

o/d ratio in the winter: $y = -0.0201x + 0.2534$ $R^2 = 0.9606$

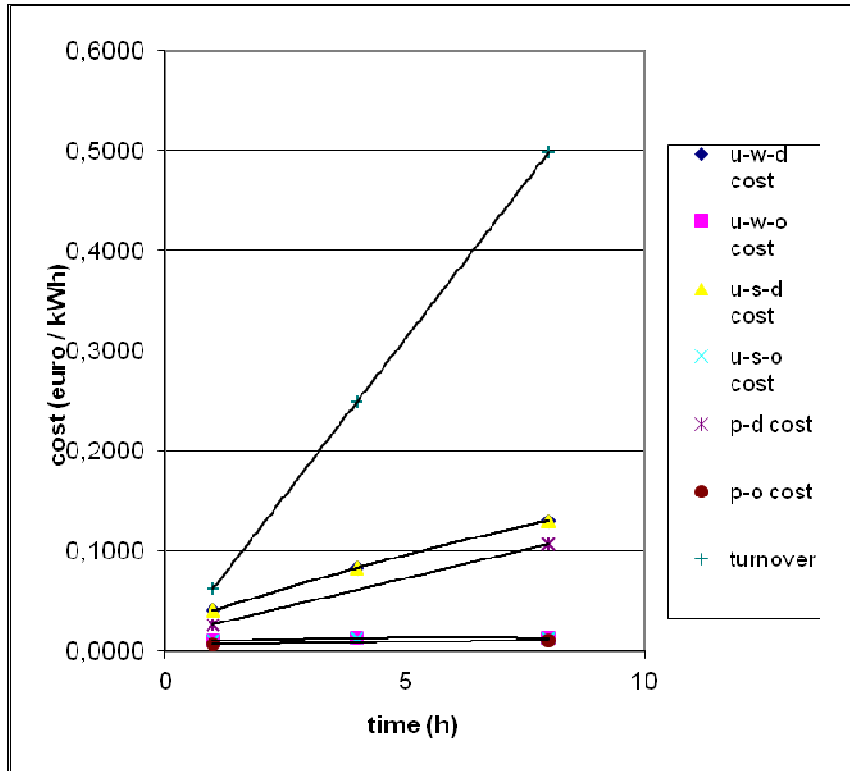


FIGURE 78: SUMMARY OF OUTAGE COST CHARACTERISTICS FOR THE HEALTH SECTOR

5.1.11 OTHERS

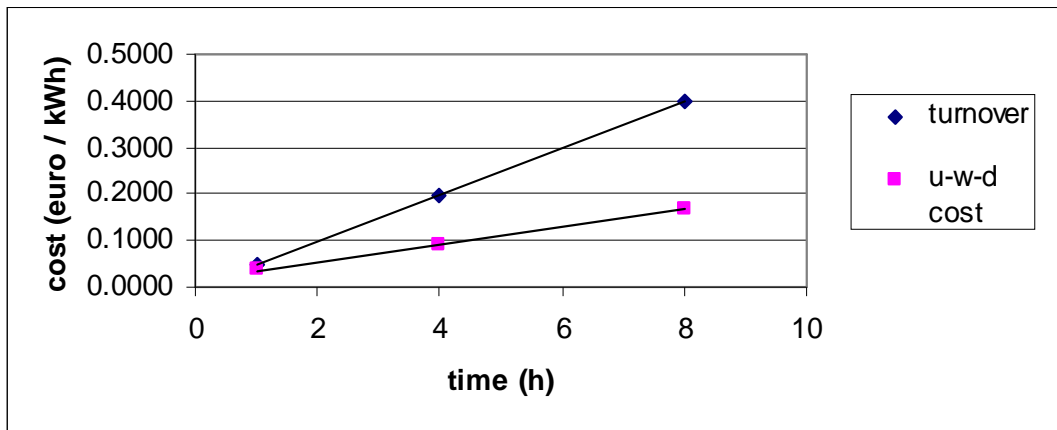


FIGURE 79: TURNOVER AND U-W-D OUTAGE COST ANALYSIS RESULTS FOR THE OTHER SECTORS

Linear regression results:

Turnover: $y = 0.0497x - 2E-16$ $R^2 = 1$

Reported u-w-d cost: $y = 0.0191x + 0.0164$ $R^2 = 0.9995$

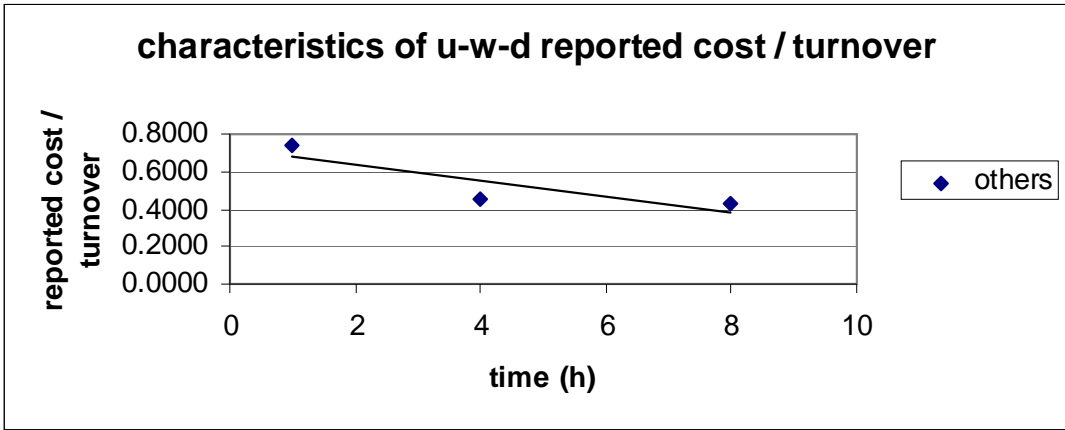


FIGURE 80: CHARACTERISTICS OF U-W-D REPORTED COST / TURNOVER FOR THE OTHER SECTORS

u-w-d reported cost / turnover : $y = -0.0419x + 0.7220 \quad R^2 = 0.7571$

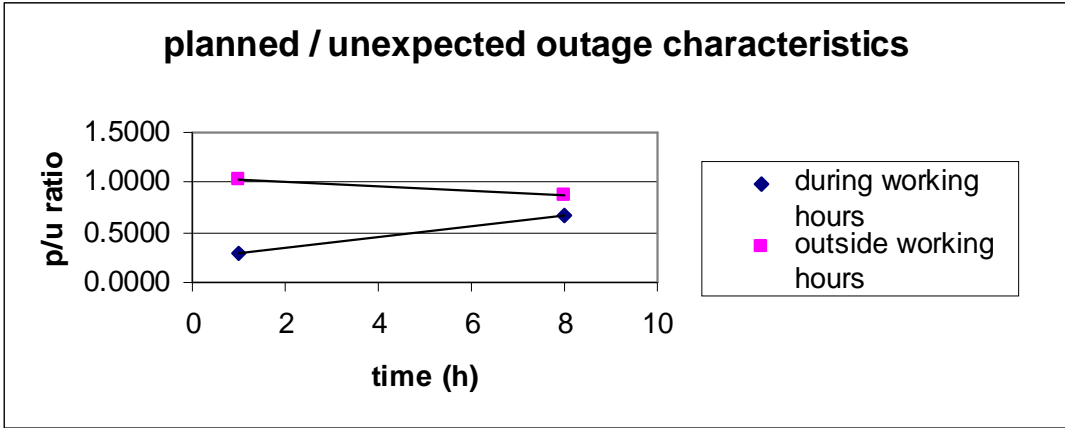


FIGURE 81: CHARACTERISTICS OF PLANNED / UNEXPECTED OUTAGE COSTS FOR THE OTHER SECTORS

p/u ratio during working hours: $y = 0.0543x + 0.2365 \quad R^2 = 1$

p/u ratio outside working hours: $y = -0.0247x + 1.0648 \quad R^2 = 1$

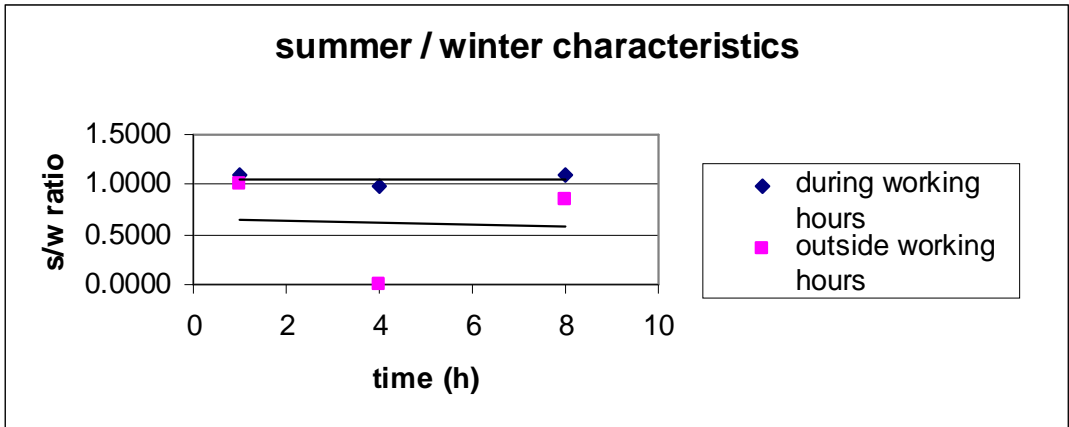


FIGURE 82: CHARACTERISTICS OF SUMMER / WINTER OUTAGE COSTS FOR THE OTHER SECTORS

s/w ratio during working hours: $y = 0.0004x + 1.0538$ $R^2 = 0.0004$

s/w ratio outside working hours: $y = -0.0101x + 0.6596$ $R^2 = 0.0044$

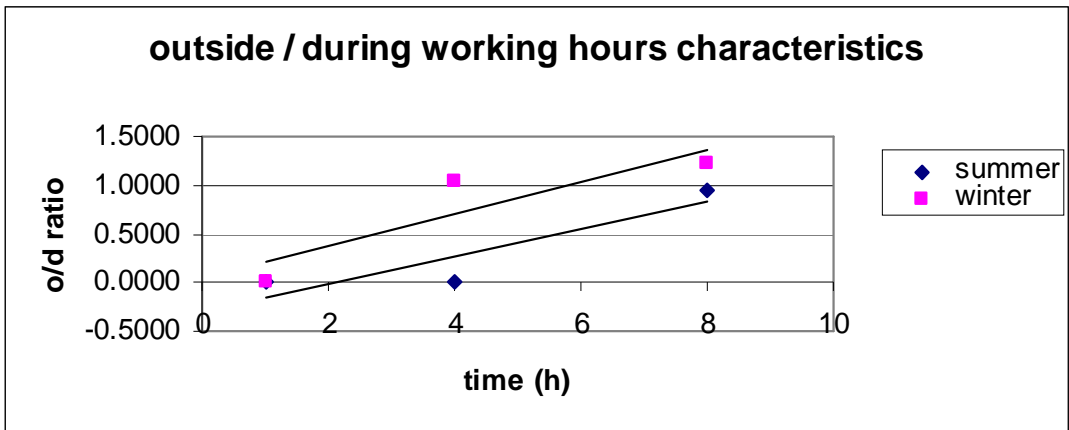


FIGURE 83: CHARACTERISTICS OF OUTSIDE / DURING WORKING HOURS OUTAGE COSTS FOR THE OTHER SECTORS

o/d ratio in the summer: $y = 0.1393x - 0.2867$ $R^2 = 0.8197$

o/d ratio in the winter: $y = 0.1662x + 0.0355$ $R^2 = 0.7899$

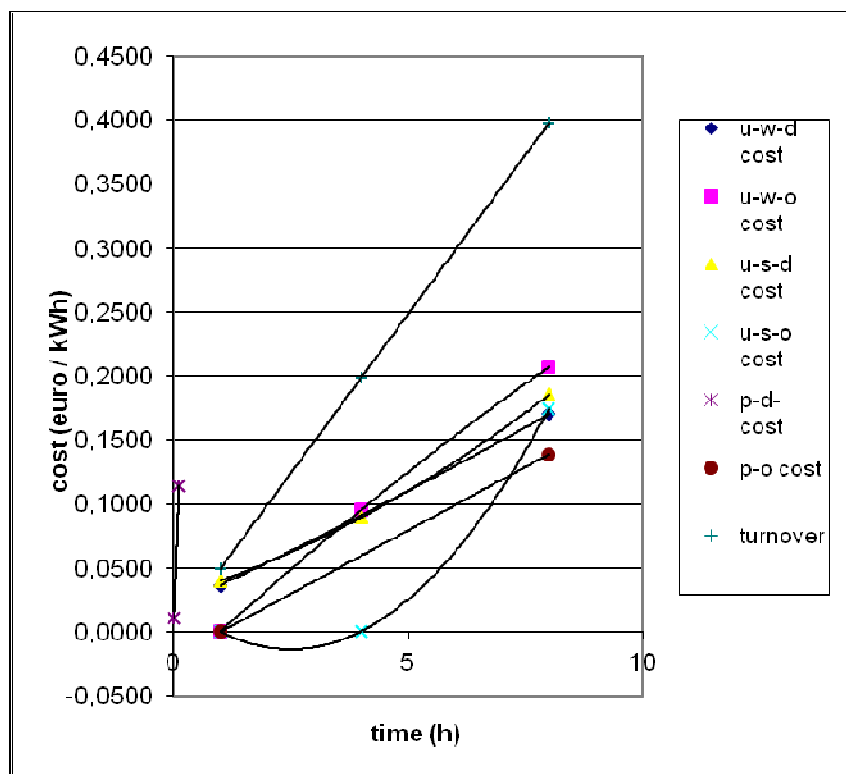


FIGURE 84: SUMMARY OF OUTAGE COST CHARACTERISTICS FOR THE OTHER SECTORS

5.2 OUTAGE COST ESTIMATION EXAMPLES FOR SERVICE SECTOR

5.2.1 EXAMPLE #1

In a certain region, a company doing business in sports sector experiences a power cut without any prior notification between 22.00 and 00.30 o'clock. The month when the outage happened is August, and the owner of this company wishes to understand his/her losses due to this interruption.

The type of the service: Sports sector

The duration of the interruption: 2.5 h

The characteristics of the interruption: unexpected outage

The season in which the outage happened: summer

The time period in which the outage happened: outside working hours

So this outage is a u-s-otype.

By referring to the Sports sector analysis, we may calculate the Reported u-w-d cost:

$$\text{Reported u-w-d cost: } y = 0.0218x + 0.0318$$

$$y = 0.0218 * 2.5 + 0.0318 = 0.0863 \text{ € / kWh}$$

Now, we are supposed to convert u-w-d cost into u-s-o cost. This means the base value must be multiplied by the s/w ratio first. Since the actual outage happens at outside working hours, one has to choose the corresponding characteristics from the s/w ratio analysis.

$$\text{s/w ratio outside working hours: } y = 0.0084x + 0.9904$$

$$y = 0.0084 * 2.5 + 0.9904 = 1.0114$$

$$\text{u-s-d cost} = \text{u-w-d cost} * \text{s/w} = 0.0863 \text{ € / kWh} * 1.0114 = 0.0873 \text{ € / kWh}$$

The cost now became a u-s-d one, now it must be multiplied by the ratio o/d to get u-s-o type outage cost result. Since the actual outage happens in the summer time, one has to choose the corresponding characteristics from the o/d ratio analysis.

$$\text{o/d ratio in the summer: } y = -0.0096x + 0.1076$$

$$y = -0.0096 * 2.5 + 0.1076 = 0.0836$$

$$\text{u-s-o cost} = \text{u-s-d cost} * \text{o/d} = 0.0873 \text{ € / kWh} * 0.0836 = 0.00073 \text{ € / kWh}$$

Finally let us assume that the customer's annual electricity consumption is 50 000 kWh, then the total loss becomes:

$$\text{CIC} = 0.00073 \text{ € / kWh} * 50\,000 \text{ kWh} = 36.5 \text{ €}$$

5.2.2 EXAMPLE #2

In a certain region, the electric supply utility informs a customer, a hotel, that there will be a power interruption between 09.15 and 13.15 o'clock. The month when the outage is planned is May, and the accounting manager of this hotel wishes to understand their losses due to this interruption.

The type of the service: Hotel sector

The duration of the interruption: 4.0 h

The characteristics of the interruption: planned outage

The season in which the outage happened: summer

The time period in which the outage happened: during working hours

So this outage is a p-s-d type.

By referring to the Hotel sector analysis, we may calculate the Reported u-w-d cost:

Reported u-w-d cost: $y = 0.0028x + 0.0033$

$$y = 0.0028 * 4.0 = 0.0112 \text{ € / kWh}$$

Now, we are supposed to convert u-w-d cost into p-s-d cost. This means the base value must be multiplied by the p/u ratio first. Since the actual outage happens during working hours, one has to choose the corresponding characteristics from the p/u ratio analysis.

p/u ratio during working hours: $y = 0.0817x + 0.0513$

$$y = 0.0817 * 4.0 + 0.0513 = 0.3781$$

$$\text{p-w-d cost} = \text{u-w-d cost} * \text{p/u} = 0.0112 \text{ € / kWh} * 0.3781 = 0.0042 \text{ € / kWh}$$

The cost now became a p-w-d one, now it must be multiplied by the ratio s/w to get p-s-d type outage cost result. Since the actual outage happens during working hours, one has to choose the corresponding characteristics from the s/w ratio analysis.

s/w ratio during working hours: $y = 0.0777x + 0.5165$

$$y = 0.0777 * 4.0 + 0.5165 = 0.8273$$

$$\text{p-s-d cost} = \text{p-w-d cost} * \text{s/w} = 0.0042 \text{ € / kWh} * 0.8273 = 0.0035 \text{ € / kWh}$$

Finally let us assume that the customer's annual electricity consumption is 265 000 kWh, then the total loss becomes:

$$\text{CIC} = 0.0035 \text{ € / kWh} * 265\,000 \text{ kWh} = 927.5$$

5.3 COMMENTS

Although making use of indirect analytical methods and using turnover / kWh cost functions seems attractive and easy to use, unlike the case as in the industry sector, the turnover data can not be trusted due to obvious reasons such as the lack of continuous production depending on continuity of electric supply while calculating the customer interruption costs for service sector customers. That is why, one needs to trust to the customer survey method at this time.

Each sector, as expected, has its own and unique characteristics in case of an interruption event. This yields the necessity of analyzing and thus estimating the outage costs of these sectors separately. In addition to this fact, the parameters affecting the interruptions costs of the service sector, and the effects of these parameters, conditions, on the costs change considerably. As a result, estimation and calculation of such costs turn out to be a rather difficult task for the professionals. In order to ease this process a methodology, which is based on the customer survey, has been developed to convert outage estimation calculations regarding the parameters of the interruptions.

As it can be seen above, the methodology presented here to estimate the power outage costs of service sector in Finland is quite straightforward, easy to understand and easy to follow. Both utilities and service sector customers can use these results for estimating their interruption costs at any situation possible just by following the steps explained above.

6 CONCLUSION

As the electric power system and markets throughout the world leaves the traditional vertically integrated and monopolistic market state, the importance of reliability and thus the number of reliability worth analysis studies increase. The continuity of supply and power quality issues is vitally important for large electric power consumers and their dependency to this power is increasing day by day. As a consequence, the outcomes of power interruptions are severe for these customers. There have been many studies for the estimation and calculation of these outcomes. As a result, many methodologies and analysis techniques have been proposed to estimate the power outage costs. However, still today, the accuracy and the reliability of these proposed methodologies are being discussed.

Having an unbundled and competitive electric market, Finland is a proper country to study power outage costs for industrial and service sector customers. In this thesis, since the power consumption and operations natures of the customer types are distinct, two different approaches are being developed for the industrial and service sector respectively based on a large and comprehensive customer survey conducted by the researchers at the Aalto University School of Electrical Engineering. The main motivating factor was to find out a methodology which is based on objective data rather than subjective and biased information. The industrial customers declare their financial information to the governments each year. The information at these reports, such as turnover, value added and annual electricity consumption, are clear, correct, easy to reach and most importantly objective. The methodology derived to estimate the power outage costs of the industrial customers includes value added per x hours, weighing factors for unexpected and planned outage and comparison of these results to the estimated costs reported by the respondents of the customer survey.

For the service sector customers, on the other hand, the situation is more complicated and more difficult to analyze. There are many parameters, such as the interruption characteristics, the interruption duration and the season, affecting the reliability worth analysis. Moreover, since one can not speak of serial production and therefore value added linearly depending on electric power, the analysis gets more tedious. As a result, instead of indirect analytical model, which is based on objective data, customer survey model has been preferred. A linear formula for each subcategory of service sector has been derived for the estimation of power outage costs.

The electric supply utilities want to know the customer interruption costs for planning and investment purposes. Official departments want to know it for legislation and applying fine reasons. And of course, the customers desire to find out their true interruption costs to see their real losses to implement precautions in order to prevent such damages. These facts clearly show the meaning and the importance of evaluating power outage costs. Therefore, in addition to the significant number of studies conducted until now, there will be more efforts to understand and calculate the power outage costs thoroughly in the future.

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