Jordan Journal of Mechanical and Industrial Engineering (JJMIE)

JJMIE is a high-quality scientific journal devoted to fields of Mechanical and Industrial Engineering. It is published by The Jordanian Ministry of Higher Education and Scientific Research in corporation with the Hashemite University.

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Editorial Preface

This is the first issue of the third volume of Jordan Journal of Mechanical and Industrial Engineering (JJMIE). JJMIE is a quarterly peer reviewed academic international journal published by the Jordanian Ministry of Higher Education and Scientific Research in cooperation with the Hashemite University for mechanical and industrial engineering sciences. The coverage of the journal includes all new theoretical and experimental findings in the fields of mechanical and industrial engineering or any closely related fields. The journal also encourages the submission of critical review articles covering advances in recent research of such fields as well as technical notes. Its mission is to provide an international forum for interdisciplinary scientific and engineering communication, to strengthen links between science and policy, and to stimulate and enhance the quality of debate. It seeks to publish articles that are not only technically competent, but are original and contain information or ideas of fresh interest to our international readership. It aims to handle submissions courteously and promptly. It welcomes dialogue with its contributors and readers.

The success we have achieved in the first two volumes was great; the number of articles we received for review from all over the world increased in steady trend. It is a great challenge to bring a new journal into the world, especially when the journal aims to publish high quality manuscripts. Despite this challenge, this journal aims to provide readers worldwide with high quality peer-reviewed scholarly articles on a wide variety of issues related to mechanical and industrial engineering. My recent discussions with distinguished scholars worldwide indicate that there is a great need for such a journal.

In order to position JJMIE as one of the most authoritative journal on mechanical and industrial engineering sciences, a group of highly valuable scholars have agreed to serve on the editorial board. I am honored to have six distinguished and active members in the editorial board, from different Jordanian Universities. I'm also delighted with our group of International Advisory Board members consisting of scholars from thirteen countries worldwide that are actively offering their valuable advice. With our editorial board's cumulative experience on engineering education, this journal brings a substantial representation of the field of mechanical and industrial engineering sciences in the disciplines noted. Without the service and dedication of our editorial board, JJMIE would have never existed.

JJMIE is committed to its own consensus. Key features of this consensus are as follows: It is committed peer review for research reports and reviews, Reviewers must keep material sent to them in strict confidence, Referees are asked to declare any conflicts of interest, It audits the quality of its peer review process in terms of time taken to respond to authors and the appropriateness of the response. It requires all named authors on a paper to have made a substantial contribution to its contents and to provide an ethical declaration. It seeks to avoid duplicate publication. It requires sources of funding for papers to be declared. It requires conflicts of interest for authors to be declared. It seeks reassurance from authors that ethical safeguards have been met in the execution of the research. It requires all those involved in the editorial process to declare potential conflicts of interest.

The editorial board policy is to select papers for publication which fall within the journal's scope and which make a significant contribution to the international research literature. Because the journal operates within a relatively fixed number of pages, and the amount of potentially publishable material exceeds that space, decisions must be made about papers in competition with others that are being considered at the time. A further aim of the editorial board is to provide a response to authors as quickly as possible. A final consideration is the need to use scarce refereeing resources as efficiently and helpfully as possible. Papers are sent to two or more referees for comment and a recommendation. Normally the editorial board will act on the basis of at least two reports. Editorial Board meeting held once a month. These involve one or more of the editorial administrators. The aim is to discuss journal strategy, evaluate gained experiences, monitor journal progress, discuss projects in which the journal is involved such as special issues, resolve outstanding problems and administrative matters and to discuss matters of policy relating to the journal and its future direction.

We recognize that the editorial process, including refereeing and decision making carries a heavy responsibility. There is a need to ensure as far as possible that what is published is accurate and represents a genuine advance in knowledge. However, there is also a responsibility to respect the rights and honest endeavor of potential contributors. This means ensuring that all those taking part respect confidentiality and intellectual property rights, that any conflicts of interest are declared, and that comments are measured, respectful and balanced.

In the coming year, it is my vision to have JJMIE publishes high quality manuscripts from a distinguished scholar on recent mechanical and industrial engineering issues. To build its international reputation, we are working on establishing ISI listing and a good impact number. The number of articles in the coming issues will be increased too. As you read throughout this inaugural volume of JJMIE, I would like to remind you that the success of our journal depends directly on the number of quality articles submitted for review. Accordingly, I would like to request your participation by submitting quality manuscripts for review and encouraging your colleagues to submit quality manuscripts for review. One of the great benefits we can provide to our prospective authors, regardless of acceptance of their manuscript or not, is the mentoring nature of our review process. JJMIE provides authors with high quality, helpful reviews that are shaped to assist authors in improving their manuscripts.

The editorial board and I very much appreciate your support as we strive to make JJMIE one of the most authoritative journals on mechanical and industrial engineering studies.

Prof. Mousa S. Mohsen
Editor–in-Chief
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Assessment of Energy and Exergy Efficiencies of Power Generation Sub-Sector in Jordan

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Abstract

The present article is dedicated for evaluating the power generation sub-sector in terms of energetic and exergetic aspects. In this regard, energy and exergy utilization efficiencies during the period 1989-2006 are assessed based on real data obtained from main generators in Jordan. Sectoral energy and exergy analyses are conducted to study the variations of energy and exergy efficiencies for each of the studied power plant, and overall energy and exergy efficiencies for the entire sub-sector are found to be in the range of 31.95 to 35.99%. When compared with other neighbouring countries, such as Turkey and Saudi Arabia, the Jordanian power sub-sector is more efficient, but the opposite was noticed as compared with some developed countries, e.g. Norway and Malaysia, for year 2000. Such difference is inevitable due to dissimilar structure of the utility sector in these countries. It is expected that that the results of this study will be helpful in developing highly applicable and productive planning for future energy policies, especially for the power sub-sector.

Keywords: Energy; Exergy; Efficiency; Utility Sector; Jordan

1. Introduction

The need to control atmospheric emissions of greenhouse and other pollutant gases and substances will increasingly shed its light on the efficiency of all energy conversion processes and applications especially power generation, transmission, distribution, and final demand represented by existing consumption patterns and technologies. On the other hand, some of known energy sources have been nearly exhausted nowadays. Hence, issues related to economic costing and efficient utilization of all natural resources, including energy, gained vital importance. For these reasons, deep analysis and evaluation of periodical data for power generation and other final energy-consuming sectors are essential, and are considered as primary conditions to accomplish some of the national goals, which are designed to achieve sustainable development in all sectors of the economy.

The present paper is among a series of practical articles, by authors, aimed to model various sectors and applications by employing insightful energy and exergy analysis [1-3], considered first of its kind in Jordan since there is no such study on energy and exergy utilizations for the power sub-sector. Thus, the prime objective of the present study is oriented towards determining energy and exergy losses and related efficiencies as first step to understand influence and weight of different factors. Furthermore, comparison of obtained results of energy and exergy efficiencies with other countries around the world will be carried out depending on published data in the open literature. As Jordan is considering and implementing the updated national energy strategy with more emphasis on energy efficiency policies in different sectors, it is believed that this investigation will provide a scientific judgment and insight to general performance of main generators and possible future improvements for energy policy implementation within the power sub-sector, and may be useful to engineers and scientists working in the field of energy in Jordan and some neighbouring countries.

2. Electricity Generation in Jordan

At present, after the privatization of the power sub-sector last year, there are three electricity generation companies in Jordan, not counting large industries such as Phosphate Mines, Arab Potash, Cement, Fertilizer Complex, Petroleum Refinery, and other plants owning and operating small and medium size power generation units [4]. Main generators in Jordan are:

2.1. Central Electricity Generation Company (CEGCO)

which was privatised at the beginning of 1999, and the state-shares were sold to Dubai Capital in 2007. It is solely an electric-power generator and main producer with total installed capacity exceeding 1700 MW.

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2.2. Samrah Power Generation Company (SPGCO)

which is a state-owned company that will be privatized in the near future, and it is a single power station utility located north-east of Amman. It is a combined cycle plant, which consists of 2x100 MW gas turbines and 100 MW steam turbine. The power station is supplied with Egyptian imported natural gas.

2.3. Manakher Power Generation Company

which is the 1st independent power producer (IPP) in Jordan located east of Amman; and is based on combined cycle technology firing imported natural gas from Egypt. The installed capacity is about 380 MW and expected to become fully on line next year, i.e. 2009.

It is worth mentioning that the government of Jordan represented by the Ministry of Energy and Mineral Resources and Electricity Regulatory Commission is in the process of licensing the 2nd IPP in Jordan; and will build and operate a combined cycle power plant in Qatranh town, about 90 km south of Amman. It is expected that this plant will become on line by 2010.

In Jordan, there are 20 power stations with a total installed capacity of 2222 MW, 99.50% is thermal, and the remaining small percentage represents hydropower and wind turbines. Most of these are owned and operated by CEGCO with an installed capacity of 1700 MW, i.e. representing 77% of the total installed capacity and generating about 80%, i.e. 8966 GWh of the produced electricity in the kingdom during 2006 [4]. The remaining percentage was provided by SPGCO, the interconnected industrial companies and electricity imports from Egypt. Recently Jordan has not faced electricity shortages, and occasionally small amount of the generated electrical power has been exported to Syria. The supply of electricity is the largest single consumer of primary energy: it accounted for around 40% of primary energy consumption during last two years, compared with only 16% in 1980 [5]. But because of conversion i.e. generation, transmission, and distribution losses the relative importance of electricity in terms of primary energy, and carbon emissions is more than twice as compared to that indicated previously. The national electrical grid is connected to Egypt through a sub-marine cable across the Gulf of Aqaba in the south, and Syria in the north, via an overhead transmission line as part of the regional interconnection plan between seven countries including Egypt, Jordan, Syria, Lebanon, Jordan, Iraq, and Turkey. At present, all of the consumed electricity is produced locally employing conventional thermal power plants. However, small quantities of about 4% and 0.5% of that consumed during 2006 were imported from Egypt and Syria, respectively [5].

Figure 1 shows the percentage of electrical energy by type of generation in 2006 (CEGCO, 2007). It is obvious that almost all generated power came out from thermal power plants, and steam power plants ranked first with sharing ratio exceeding 53% of total generated power. This was followed by combined cycle power plants and gas turbines. Others, which represent only 0.5%, include wind, biogas, and hydro power units. About 99.4% of total electricity generated in 2006 by CEGCO came out from four power plants: Aqaba thermal, Hussein thermal, Risha, and Rehab with total productions of 3740, 1602, 657, and 2435 GWh, respectively. Before 2003, heavy fuel oil (HFO) was the dominant fuel used in the power sub-sector because the two main power stations, Aqaba and Hussein, are conventional thermal plants employing Rankine steam cycle; and are fired by such an inexpensive fuel. However, since 2003, imported natural gas from Egypt replaced HFO in Aqaba power station. In early 2006 diesel fuel at Rehab and Samrah power plants were replaced. In 2006, about 80.1% and 19.3% of the total electricity generated was produced using NG and HFO, respectively. While diesel fuel share dropped to less than 1% due to its substitution by natural gas in Rehab and Samrah power stations. Electricity harnessed via renewable sources like hydropower and wind accounted for only a negligible percentage of the total electricity generated (CEGCO, 2007). The dominant role of steam turbines, diesel-fuel fired gas-turbines, and combined cycle power plants is leading to increased dependence on imported natural gas and oil. Less than 8% of the electrical-power generation, at present in Jordan, arises from the exploitation of the indigenous domestic natural gas from the Risha field.

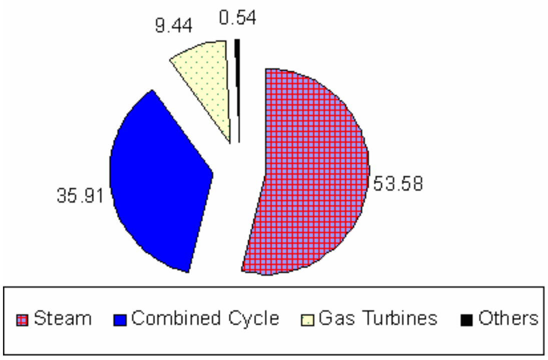

Figure 1 : Generated electrical energy in Jordan by type of generation in 2006.

The system's peak load in 2006 was 1901 MW, compared with 1751 MW in the previous year (2005) with a growth rate of 8.6%. The peak load used to occur during last three decades, late in the summer, i.e. during the July-September period. This is due to the excessive use of air-conditioning and ventilation systems as a result of the dry climate and high temperatures, as well as being the holiday season for tourists and many returning Jordanians, who normally work abroad. However, during the last few years, 2005-2007, the peak occurs during winter time because the government raised unit prices of petroleum products in an attempt to remove state-subsidy from various energy forms and ensure the full coverage of the economic costs involved. But the government postponed increasing the prices of electricity in order to enable consumers in the local market to absorb this price shock, and sooner or later prices of electricity and other strategic commodities will be increased. This is considered as a misleading message to the public, who will use high grade energy, i.e. electricity, for space heating purposes in different sectors instead of traditional petroleum products, i.e. kerosene, diesel, or LPG [6].

3. Energy and Exergy Modelling

In order to compare the quality levels of various energy carriers, e.g. fuels, it is necessary to determine the equivalents of each energy quantity at a particular grade level. This can be done by using exergy concept, which overcomes the limitations of the first law of thermodynamics; and is based on both the first and the second law of thermodynamics [7-8]. An exergy analysis can identify locations of energy degradation and rank them in terms of their significance [9]. This knowledge is useful in directing the attention of process design, researchers, and practicing engineers to those components of the system being analyzed that offer the greatest opportunities for improvement. Furthermore, exergy analysis has been used to analyze energy utilization on the national level and for various sectors of the economy in order to better understand energy utilization efficiency. This approach was first used by [10] who applied it to the overall U.S. economy in 1970. Since then, it has been adopted by several researchers for other countries such as Japan [11], Canada [12], and Brazil [13]. A summary of exergy analyses for different countries can be found in [14]. The concept has been also applied to cross-country analysis of some industrial segments [15-19], residential sector [20, 1], transportation sector [21-24, 2], agricultural sector [25-26, 3], and utility sector [27-29]. The purpose of this section is to discuss the main mathematical relations necessary to conduct energy and exergy analyses in the utility sector.

3.1. Exergy Calculation

By describing the use of energy resources in society in terms of exergy, important knowledge and understanding can be gained, and areas can be identified where large improvements could be obtained by applying efficient technology in the sense of more efficient energy-resource conversions. In principle, the exergy matter can be determined by bringing it to the dead state by means of reversible processes. The basic formulas used in exergy analysis modelling for this study are given below.

3.1.1. Exergy of Fuel

The specific exergy of the fuel at environmental conditions reduces to chemical exergy, which can be written as:

$$\varepsilon_f = \gamma_f H_f , \quad (1)$$

where ε_f is the fuel specific exergy, γ_f the exergy grade function, and H_f the higher heating value of the fuel. Table 1 shows higher heating value, chemical exergy, and fuel exergy grade function of different fuels considered in this study [8, 10, 19, and 30]. As shown, in Table 1, all values of the exergy grade function are very close to unity. Consequently, the common practice in such cases is to assume that the exergy of the fuel is approximately equal to the higher heating value [31-32].

3.1.2. Exergy of Electricity

From the definition of exergy, electricity, W_e, is identical to the physical work exergy, E^{We}:

$$E^{We} = W_e , \quad (2)$$

Table 1 : Higher heating value, chemical exergy, and exergy grade function for different fuels (at 25°C and 1 atm) [8, 10, 19, 30].

Fuel	H_f (kJ/kg)	ε_f (kJ/kg)	γ_f (ε_f /H_f)
Diesel	39,500	42,265	1.070
HFO	40,600	40,194	0.990
Natural Gas	55,448	51,702	0.930

3.2. Energy and Exergy Efficiencies

Energy efficiency (first law efficiency) is the ratio of energy contained in useful products of a process to energy contained in all input streams, while exergy efficiency (second law efficiency) is the ratio of exergy contained in the useful product to the exergy contained in all input streams. Energy efficiency (η) and exergy efficiency (ψ) are defined as:

$$\eta = \left(\frac{energy\ in\ products}{total\ energy\ input} \right) \times 100\% \quad (3)$$

$$\psi = \left(\frac{exergy\ in\ products}{total\ exergy\ input} \right) \times 100\% \quad (4)$$

Energy, η_e, and exergy, ψ_e, efficiencies for electricity generation through fossil fuels, m_f, can be expressed as follows:

$$\eta_e = (W_e /(m_f H_f)) \times 100\ \% \quad (5)$$

$$\psi_e = (E^{We} /(m_f \varepsilon_f)) \times 100\% = (W_e /(m_f \gamma_f H_f)) \times 100\% = \eta_e \quad (6)$$

Therefore, exergy efficiency for electricity generation process can be taken as equivalent to the corresponding energy efficiency [32].

4. Results and Discussion

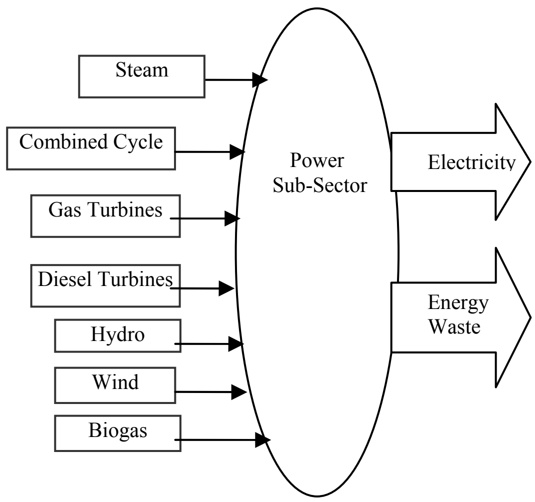

Figure 2 : An illustrative presentation of electricity production in Jordan.

As stated previously, electricity is mainly produced by means of thermal power plants in addition to small portions produced by using available renewable sources. Figure 2 shows an illustrative presentation of electricity production in Jordan. In order to simplify the analysis of energy and exergy efficiencies for this sector, energy consumption and electric production flows are analyzed for four power plants namely steam, combined cycle, gas turbines, and diesel engines that consume most of fuels, i.e. 99.5%, supplied to the power sub-sector.

Real data from the field has been obtained by compiling and analyzing scattered data collected from CEGCO, NEPCO, and SPGCO for a period spanned from 1989 to 2006 [4-5, 33]. This forms a unique point in this study by developing a comprehensive data, which is not published elsewhere. Tables 2 and 3 show energy consumption and electricity generation, respectively for each of studied four power stations.

Table 2: Primary energy consumption according to type of generator during the period 1989-2006 (1000 toe).

Year	Overall	Steam units	Gas turbines	Diesel engines	Combined cycle
1989	752.56	655.28	76.50	20.79	0.00
1990	813.20	681.76	117.09	14.35	0.00
1991	846.58	710.56	119.31	16.71	0.00
1992	1029.76	860.41	141.76	27.64	0.00
1993	1138.67	931.46	177.14	30.08	0.00
1994	1253.87	948.93	281.45	23.49	0.00
1995	1343.24	1016.21	308.01	19.02	0.00
1996	1448.85	1068.94	360.09	19.80	0.00
1997	1527.64	1065.74	443.08	18.83	0.00
1998	1632.09	1206.03	406.56	19.49	0.00
1999	1617.40	1355.63	260.02	1.75	0.00
2000	1686.09	1443.03	242.51	0.56	0.00
2001	1706.44	1471.99	234.05	0.40	0.00
2002	1808.04	1580.80	226.52	0.72	0.00
2003	1850.35	1558.55	291.51	0.28	0.00
2004	2118.57	1763.88	354.23	0.45	0.00
2005	2246.18	1860.12	273.90	0.51	111.65
2006	2183.13	1439.00	296.37	0.82	446.94

Table 3: Electricity generation according to type of generator being employed during 1989-2006 (GWh).

Year	overall	Steam units	Gas turbines	Diesel engines	Combined cycle
1989	3028.08	2657.03	282.14	88.91	0.00
1990	3246.43	2751.23	434.10	61.10	0.00
1991	3334.14	2835.25	428.13	70.75	0.00
1992	4001.92	3400.76	484.77	116.39	0.00
1993	4361.62	3628.91	608.56	124.15	0.00
1994	4658.56	3599.68	959.86	99.02	0.00
1995	5174.91	4057.36	1036.82	80.73	0.00
1996	5621.64	4319.54	1218.13	83.97	0.00
1997	5883.04	4269.40	1534.44	79.20	0.00
1998	6280.59	4847.29	1352.52	80.78	0.00
1999	6632.96	5745.43	880.82	6.72	0.00
2000	6901.13	6078.95	820.32	1.85	0.00
2001	7093.50	6240.92	851.23	1.35	0.00
2002	7568.46	6770.52	795.33	2.60	0.00
2003	7439.03	6430.20	1007.87	0.95	0.00
2004	8409.07	7168.12	1239.52	1.43	0.00
2005	9042.81	7524.22	958.33	1.86	558.40
2006	8924.92	5730.93	1010.24	3.05	2180.70

As can be seen from these tables, both fuel consumption and electricity generation were increased three times during the study period. More importantly, is the introduction of combined cycle fired by imported natural gas two years ago, i.e. 2005. This will have a dramatic effect on the performance of the power sub-sector in Jordan since it has the highest efficiency as compared with other available thermal technologies of power generation.

The analysis has been carried out based on input and output energies and exergies given in Tables 2 and 3. Energy and exergy efficiencies for each year have been determined by using equations 5 and 6, considering energy grade function as unity. The overall efficiency has been estimated by dividing total electrical energy produced by the total input energy. A sample calculation for the year 2006 was developed and provided in Appendix I: Table 4 shows both of energy and exergy efficiencies for the whole sub-sector and studied four power plants.

Table 4: Calculated energy and exergy efficiencies during 1989-2006 (%).

Year	Overall	Steam units	Gas turbines	Diesel engines	Combined cycle
1989	34.60	34.87	31.71	36.77	
1990	34.33	34.70	31.88	36.62	
1991	33.86	34.31	30.86	36.42	
1992	33.42	33.99	29.40	36.21	
1993	32.94	33.50	29.54	35.49	
1994	31.95	32.62	29.32	36.25	
1995	33.13	34.33	28.94	36.49	
1996	33.36	34.75	29.09	36.46	
1997	33.11	34.45	29.78	36.17	
1998	33.09	34.56	28.60	35.63	
1999	35.26	36.44	29.13	33.02	
2000	35.19	36.22	29.09	28.41	
2001	35.74	36.46	31.27	29.14	
2002	35.99	36.83	30.19	31.25	
2003	34.57	35.48	29.73	28.88	
2004	34.13	34.94	30.09	27.09	
2005	34.62	34.78	30.08	31.11	43.00
2006	35.15	34.24	29.31	32.07	41.95

In general, for the utility sector, several investigators have come up with the same results that energy and exergy efficiencies for similar activities are almost identical for the power sub-sector sector. This result indicates that inefficiencies in this sector are not caused by mismatch in the input-output quality levels but rather by the presently available techniques used for conversion processes. Substantial improvements in this sector are expected to be difficult to obtain, and will involve major changes in the conversion methods [32].

Although the sectoral coverage is different for each country, it is useful to illustrate how energy and exergy efficiencies vary. A comparison of the calculated overall energy and exergy efficiencies of the national power sub-sector with other countries was carried out for year 2000 since sectoral published data available for this particular year [27-29, 34]. Figure 3 shows energy and exergy efficiencies for selected countries. It can be seen that the local power sub-sector is found to be less efficient than that of Norway. Such large difference can be attributed to the fact that Norway has no thermal power plants and has relatively large contributions from Hydro-power units. Therefore, irreversibilities or exergy losses of its power sub-sector are minor as compared to the case of Jordan, which enjoys exactly the opposite: where it has a major contribution from thermal power plants while hydro-electricity is negligibly small. Although, the contribution of hydro-electricity is large in the Turkish utility sector of about 25% [29], energy and exergy efficiencies are slightly lower than those occurred locally because of relatively low efficiency of thermal power plants fuelled by hard coal. Again, energy and exergy efficiencies for the Malaysian power sub-sector are slightly higher than that of Jordan due to significant contribution, i.e. about 10%, of hydro-power [28]. When compared to Saudi Arabia for the same year, energy and exergy efficiencies of the Jordanian utility sector were higher. Such slight difference can be attributed to increased role of gas turbines, as simple cycle, in the Saudi electrical system and sea water desalination as part of main thermal power plants.

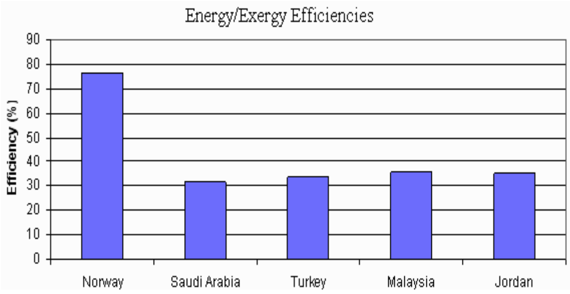

Figure 3 : Comparison of energy and exergy efficiencies of the utility sector of Jordan with other countries for the year 2000.

For comparison purposes, energy and exergy efficiencies for main generating plants for year 2006 are indicated in Figure 4. It is obvious that combined cycle units have the highest values. This should attract the attention of planners and policy makers to upgrade all existing power plants based on gas turbines to operate as combined cycle in the near future. Moreover, future expansion in power generation projects should be limited to combined cycle plants, especially when fired with natural gas. Such trend has the extra advantage of reducing total gaseous emissions, including greenhouse gases from the power sub-sector [35].

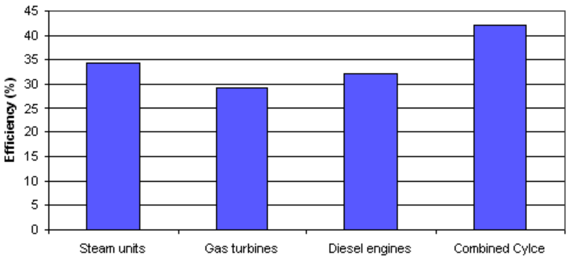

Figure 4 : Energy and exergy efficiencies of power plants of the utility sector in Jordan for the year 2006.

5. Conclusions

In this study, energy and exergy efficiencies of the Jordanian utility sector were determined for period spanning from 1989 to 2006. Calculated exergy efficiency of the power sub-sector sector is the same as its corresponding energy efficiency since for fossil fuels energy, which is the prime energy source for electricity production in Jordan, the exergy grade function is almost unity. The average overall energy and exergy efficiencies are found to be about 34.14%. Comparing obtained results with other countries shows that the local power sub-sector energy and exergy efficiencies are slightly better than those incurred in Saudi Arabia and Turkey. But these efficiencies were far less than those reported for the Norwegian and Malaysian power sub-sectors due to differences in the structure and technologies being employed in these countries.

The calculated efficiencies over the studied period can be considered as an important tool for policy makers, energy planners, and operators to get deeper insight into the performance of the power sub-sector. Furthermore, such results could provide important guidelines for future research work since large energy and exergy losses, which are reported in this study, should be taken as a challenge by the society, and concerned governmental institutions and generators achieve sustainability goals.

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Appendix

A sample calculation of energy and exergy efficiencies of the Jordanian utility sector for the year 2006 was developed and provided as follows:

1- For steam power plant:

$$\eta_e = W_e/(m_f H_f) = \psi_e = (5730.93GWh/(1439.00\times10^3 toe))\times100\% = 34.24\%$$

2- For gas turbines plants:

$$\eta_e = W_e/(m_f H_f) = \psi_e = (1010.24GWh/(296.37\times10^3 toe))\times100\% = 29.31\%$$

3- For Diesel engines plants:

$$\eta_e = W_e/(m_f H_f) = \psi_e = (3.05GWh/(0.82\times10^3 toe))\times100\% = 32.07\%$$

4- For combined cycle plants:

$$\eta_e = W_e/(m_f H_f) = \psi_e = (2180.7GWh/(440.94\times10^3 toe))\times100\% = 41.95\%$$

5- Overall plants:

$$\eta_e = W_e/(m_f H_f) = \psi_e = (8924.92GWh/(2183.13\times10^3 toe))\times100\% = 35.15\%$$

Similarly, calculations for the remaining years have been made using the same method. Table 4 shows both of energy and exergy efficiencies for the whole sub-sector and studied four power plants.

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Fuzzy Genetic Approach to Economic Lot – Size Scheduling Problem

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Abstract

The aim of this paper is to consider formulation of Economic Lot size Scheduling Problem (ELSP) in fuzzy environment with fuzzy inventory costs and objective goal. A Genetic Algorithm (GA) is used to solve the problem in the sense that it is computationally simple, yet powerful in its search for improvement. This approach is defined as Fuzzy Genetic Approach (FGA). The ELSP is a problem of scheduling the production of several different items over the same facility on a repetitive manner. The facility is such that only one item can be produced at a time. The ELSP formulation in-turn is considered under the Basic Period (BP) approach with the cycle time, T_i, of each item modified and expressed as a real multiple k_i of a fundamental cycle T. As the typical inventory analysis in the real world situations is sensitive to reasonable errors in the measurement of relevant inventory costs, the inventory costs are assumed to be vague and imprecise in this paper. The objective of minimizing the total inventory cost is also imprecise in nature. The impreciseness in these variables has been represented by fuzzy linear membership functions. The bench mark problem of Bomberger's ELSP has been worked out to highlight the method, and the results are compared with those of corresponding crisp model results. The results indicate that the FGA gives good results and works better even for higher utilization levels of the ELSP.

Keywords: Inventory; Economic lot size scheduling; fuzzy variable; membership function; Genetic Algorithm

1. Introduction

The Economic Lot Size Scheduling Problem (ELSP) is practically important; and is a problem of scheduling production of multiple items over the same facility or machine on a repetitive basis. Examples of ELSP situations include producing several different colors of paint on the same equipment and producing several types of stamped metal parts with the same stamping press. Since items must all be made on the same facility, production of an item will be in lots or batches. The production cycle time T_i of the ith item, therefore, is the elapsed time between productions of consecutive lots of the same item. The facility is such that only one item can be produced at a time, there is a setup cost and setup time associated with each item. The demand rate for each item is known and constant, no shortages are allowed, and for each item the total variable cost is the sum of its setup cost and a time and quantity dependent inventory holding cost.

As the ELSP is NP hard, due to the difficulty of checking the feasibility of schedule, some researchers developed approaches in which additional constraints that guarantee feasibility are added to the problem. Such approaches include the common cycle (CC) approach attributed to Hanssmann [1], and the BP approach attributed to Bomberger [2]. Jones and Inman [3] have provided a detailed analysis of conditions under which the CC approach provides optimal or near – optimal solutions. Doll and Whybark [4] used heuristic approaches which have been effective in approaching the optimal solution to the benchmark problem of Bomberger than analytical approaches. However, they lack a systematic way to test for feasibility and efficient procedures to escape from infeasibility.

The Basic period (BP) approach guarantees feasibility by making the cycle time of each product an integer multiple of a basic cycle time known as the fundamental cycle. Thus the BP approach results in a problem that has one continuous decision variable (the fundamental cycle) and a number of integer decision variables (the integer multipliers) equal to the number of products. Bomberger [2] formulated the problem as a Dynamic Programming (DP) problem, and solved the ELSP under the BP approach.

An excellent review of the literature on the ELSP up to 1976 is given by Elmaghraby [5]. Since then, many new approaches to the problem have been proposed. Khouja et

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al. [6] investigated the use of GAs for solving the ELSP. The problem is formulated using the BP approach and solved by using a binary coded GA. The GA is tested on Bomberger's classical problem. Ben-Daya and Hariga [7] modeled the effect of imperfect production processes on the ELSP by taking into account the imperfect quality and process restoration. Torabi et al. [8] addressed the common cycle multi-product lot-scheduling problem in deterministic flexible job shops where the planning horizon is finite and fixed by management. To solve the problem, a mixed integer nonlinear program is developed which simultaneously determines machine allocation, sequencing, lot-sizing, and scheduling decisions.

Yao and Huang [9] solved the ELSP with deteriorating items using the extended basic period approach under Power-of-Two (PoT) policy. Teunter et al. [10] studied the ELSP with two sources of production: manufacturing of new items and remanufacturing of returned items. For both cases, a mixed integer programming formulation is presented for a fixed cycle time, and simple heuristics are proposed. Jenabi et al. [11] addressed ELSP in flexible flow lines with unrelated parallel machines over a finite planning horizon. A mixed zero-one nonlinear mathematical programming method has been developed for solving the problem.

Chatfield [12] developed a Genetic Lot Scheduling (GLS) procedure which combines an extended solution structure with a new item scheduling approach, allowing a greater number of potential schedules to be considered. It maintains solution feasibility determination by employing simple but effective sequencing rules that create nested schedules. He created a binary representation of formulation and utilized a GA to search for low cost ELSP solutions. Yao et al. [13] solved the economic lot scheduling problem with fuzzy demands in order to cope with the uncertainty in demand of items. Chang et al. [14] presented fuzzy extension of ELSP for fuzzy demands via the extended basic period approach and power-of-two policy.

In this paper the ELSP, under the BP approach with cycle time T_i of each item modified and expressed as a real multiple k_i of a fundamental cycle T, is formulated in both crisp and fuzzy environments. The fuzzy concept is considered for ordering costs, carrying costs, and the limitation on total cost. The impreciseness in these variables is represented by linear membership functions. A real coded GA (RGA) is used in search for the near – optimal solution to both the crisp and fuzzy ELSPs. The methodology is illustrated with a bench mark ELSP of Bomberger [2], and the fuzzy results (by FGA) are compared with those obtained by crisp analysis.

2. Problem Formulation

The following assumptions apply to the ELSP under consideration:

1. Only one item can be produced at a time on the machine.
2. Production rates are deterministic and constant.
3. Product demand rates are deterministic and constant.
4. No shortages are allowed.
5. Product setup costs and times are independent of production sequence.
6. Inventory costs are directly proportional to inventory levels.
7. The total variable cost consists of the sum of setup costs and inventory holding costs of all products.

The notations followed are given by:
i = a product or item index.
n = Number of products or items.
Z_i = Annual demand for item-i (units / unit time)
P_i = Annual production rate for item-i (units / unit time)
c_{ci} = Holding cost for item-i-per unit per unit time
c_{ri} = Setup cost of item-i per setup.
t_i = Setup time per setup for item-i.
T_i = cycle time of ith item.

2.1. Crisp Formulation

Under the BP approach, the cycle time T_i for every item is an integer multiple k_i of a fundamental cycle T. Thus, the cycle time T_i for item – i is $T_i = k_iT$. In this paper, each T_i is considered as a real multiple k_i of fundamental cycle time T. Then the crisp formulation of ELSP is given by:
Minimize: Total cost,

$$fbp = \sum_{i=1}^{n}\left[\frac{c_{ri}}{k_iT} + \frac{Z_iTk_iC_{ci}}{2}\left(1-\frac{Z_i}{P_i}\right)\right] \quad (1)$$

$$\text{Subject to}: \sum_{i=1}^{n}\left[t_i + \frac{Z_iTk_i}{P_i}\right] \le T \quad (2)$$

And $k_i > 0$; $T > 0$

The ELSP thus becomes a problem with k_i and T as decision variables. The constraint (eq.2) ensures that the fundamental cycle time is long enough to accommodate the production of all items even though not every item has to be produced during every fundamental cycle. This formulation is ideally suited for using real coded GA as all k_is are expressed as real variables. The bounds of each k_i are set by using the procedure outlined below:

Step-1: Determine T_i^* for each product by independent solution (IS) method. T_i^* is obtained by substituting Ti=kiT in eq.(1), and then differentiating and equating it to zero.

$$T_i^* = \sqrt{\frac{2c_{ri}}{Z_ic_{ci}\left(1-\frac{Z_i}{P_i}\right)}}$$

Step-2: Select the smallest T_i^* as the initial estimate of the fundamental cycle time.
i.e., T = Min.[T_i^*]

Step-3: Determine the possible integer bounds of each k_i defined by:

$$k_i^{(l)} \le \frac{T_i^*}{T} \le k_i^{(u)}$$

Where $k_i^{(l)}$, $k_i^{(u)}$ are lower and upper bounds of k_i.

2.2. Linear Membership Function

A membership function $\mu_{Ai}(x)$, assumed to be linearly increasing over the tolerance interval p_i can be expressed according to Zimmermann [15] as:

$$\mu_{Ai}(x)=\begin{cases}1 & if\ x<d_i\\ 1-\dfrac{x-d_i}{p_i} & if\ d_i\le x\le (d_i+p_i)\\ 0 & if\ x>(d_i+p_i)\end{cases} \quad (3)$$

where d_i and $(d_i + p_i)$ are the tolerance limits for x.
Introducing a new variable, α, which corresponds essentially to $\mu_{Ai}(x)$, the corresponding fuzzy variable ′x′ at the defined aspiration level ′α′ is given by:

$$\mu_{Ai}^{-1}(\alpha)=d_i+(1-\alpha)p_i \quad (4)$$

Similarly a membership function $\mu_{Bj}(x)$, assumed to be linearly decreasing over the tolerance interval p_j can be expressed as:

$$\mu_{Bj}(x)=\begin{cases}1 & if\ x>d_j\\ 1-\dfrac{d_j-x}{p_j} & if\ (d_j-p_j)\le x\le d_j\\ 0 & if\ x<(d_j-p_j)\end{cases} \quad (5)$$

Hence, $\mu_{Bj}^{-1}(\alpha)=d_j-(1-\alpha)p_j$

2.3. Fuzzy Formulation

The fuzzy set concepts are adopted for ordering costs, holding costs, and limitation on total cost. The impreciseness in these variables has been expressed by linear membership functions. Considering the nature of the variables, the membership functions are assumed to be non-decreasing for fuzzy inventory costs, and non-increasing for fuzzy total cost. On applying fuzzy non-linear programming approach to the crisp model, the formulation is:

Maximize: α

Subject to:

$$\sum_{i=1}^{n}\left[\frac{\mu_{cri}^{-1}(\alpha)}{k_iT}+\frac{Z_iTk_i}{2}\mu_{cci}^{-1}(\alpha)\left(1-\frac{Z_i}{P_i}\right)\right]-\mu_{fbp}^{-1}(\alpha)\le 0$$

i.e.,

$$\sum_{i=1}^{n}\left[\frac{(c_{ri}-(1-\alpha)\ p_{cri})}{k_iT}+\frac{Z_iTk_i}{2}(c_{ci}-(1-\alpha)\,p_{cci})\left(1-\frac{Z_i}{P_i}\right)\right]-(fbp+(1-\alpha)\,p_{fbp})\le 0 \quad (6)$$

$$\text{and}\quad \sum_{i=1}^{n}\left[t_i+\frac{Z_iTk_i}{P_i}\right]\le T \quad (7)$$

$$0\le\alpha\le 1$$

3. Genetic Algorithm

A GA performs a multi directional search by maintaining a population of potential solutions and encourages information formation and exchange between these directions. The population undergoes a simulated evolution: at each generation the relatively "good" solutions reproduce, while the relatively "bad" solutions die. To distinguish between different solutions, we use an objective (evaluation) function which plays the role of an environment.

The initial population of solutions is created by random selection of a set of chromosomes (solutions). Once a chromosome is created, it is necessary to evaluate the solution, particularly in the context of the underlying objective and constraint functions. The evaluation of a solution means calculating the objective function value and constraint violations. After assigning a relative merit to the solutions (called the fitness), the population of solutions is modified to create hopefully a better population. In this process the three main operators, viz., reproduction, crossover, and mutation are used. This completes the generation of the GA. Then a new population of solutions is created and the above procedure is repeated until the required conditions are satisfied.

The binary representation of decision variables used in genetic algorithms has some drawbacks when applied to multi-dimensional, high precision numerical problems. Real coded or floating – point representation, on the other hand, has a rising usage because of the empirical findings that real codings have worked well in a number of practical problems. The procedure of proposed GA is shown in figure 1. The Components of the developed system is discussed in the following sections.

3.1. Representation and Initialization of Population of Solutions

As a real parameter GA is used, the variables are represented by floating point numbers over whatever range is deemed appropriate. That is, the process of finding an optimal solution to a problem starts by defining a chromosome (solution) as an array of variable values to be optimized. If the chromosome has n variables (an n-dimensional optimization problem) given by $k_1, k_2, \ldots\ldots k_{10}, T, \alpha$, a chromosome is written as an array with 1 × n elements so that

$$\text{Chromosome} = [k_1, k_2, \ldots\ldots k_{10}, T, \alpha] \quad (8)$$

Procedure Genetic Algorithm
Begin
t ← 0
initialize population (t)
evaluate population (t)
while (**not** terminate – condition) **do**
begin
t ← t + 1
reproduction
crossover
mutation
evaluate population (t + 1)
end
end

Figure 1: Procedure of GA

All variables are normalized to have values between 0 and 1, the range of a uniform random number generator. Then the values of a variable are "un-normalized" in the fitness function. If the range of values of an i^{th} variable is between k_i^l and k_i^u, then the un-normalized value is given by:

$$k_i = \left(k_i^u - k_i^l\right) k_i^{norm} + k_i^l \quad (9)$$

where k_i^{norm} = Normalized value of variable, $0 \le k_i^{norm} \le 1$

Now to begin the GA, a population of s_p chromosomes is defined by a matrix with each row in the matrix being 1 × 12 array of continuous values.

3.2. Evaluation of Solutions

Once a chromosome (or a solution) is created, it is necessary to evaluate the solution, particularly in the context of the underlying objective and constraint functions. The evaluation function is called the fitness function. In most of the constrained optimization problems, the fitness function is obtained by adding a penalty proportional to the constraints' violations to the objective function value. The penalty term with respect to a constraint violation is nothing but a user defined penalty parameter multiplied by some function of the constraint. However, this method has two difficulties – fixing a penalty parameter, convergence of fitness function to an artificial local optimum. A modified version of this method, which does not need any penalty parameter, is followed in the present paper for the evaluation of fitness function. The method is based on feasible over infeasible solutions.

The method of feasible over infeasible solutions [16] employs a tournament selection operator in which two solutions are compared at a time, and the following scenarios are always assured:

1. Any feasible solution is preferred to any infeasible solution.
2. Among two feasible solutions, the one having smaller constraint violation is preferred.
3. Among two infeasible solutions, the one having a smaller constraint violation is preferred.

Motivated by these arguments, the following fitness function (F_i) is used for any ith solution of the population.

$$F_i = \begin{cases} fbp_i, & \text{if solution is feasible} . \\ fbp_{max} + \sum_{j=1}^{2} \langle g_j(X) \rangle, & \text{otherwise} \end{cases} \quad (10)$$

where fbp_i is the objective function value of ith solution. The parameter fbp_{max} is the objective function value of the worst feasible solution in the population. The g_j is jth constraint of greater than or equal to type, and the bracket operator < > denotes the absolute value of the operand, if the operand is negative. Otherwise, if the operand is non negative, it returns a value of zero. It is to be noted that the objective function value is not computed for any infeasible solution. Since all feasible solutions have zero constraint violation and all infeasible solutions are evaluated according to their constraint violations only, both the objective function value and constraint violation are not combined in any solution in the population. Thus, there is no need to have any penalty parameter for this approach.

After all, the solutions in the population are evaluated in terms of their fitness value. They are ranked in the order of best to worst solutions, and the termination condition is checked. The termination criterion is maximum number of generations to be used. If the termination criterion is not satisfied, then the three genetic operators are applied to improve the population of solutions.

3.3. Genetic Operators

The three genetic operators to be applied to improve the population of solutions are selection, crossover, and mutation operators.

3.3.1. Selection Operator

The primary objective of the selection or reproduction operator is to make duplicates of good solutions and eliminate bad solutions in a population, while keeping the population size constant. A tournament selection scheme is used where two solutions at a time are compared, and the best in terms of objective function value is selected [17]. That is, the scheme works in such a way that it picks randomly 2 individual solutions from the population and copies the best individual (in terms of fitness value) into the intermediate population; called the mating pool. This process is repeated population number of times. The mating pool, being comprised of tournament winners, has a higher average fitness than the average population fitness. This fitness difference provides the selection pressure, which drives the GA to improve the fitness of each succeeding generation.

3.3.2. Crossover Operator

Crossover using SBX operator is performed [18]. The procedure of computing offspring solutions $y^{(1)}$and $y^{(2)}$ from two parent solutions $x^{(1)}$, $x^{(2)}$ are as follows:

1. Create a random number between 0 and 1.
2. Find a parameter $\bar{\beta}$ using a polynomial probability distribution as given by:

$$\bar{\beta} = \begin{cases} (\alpha u)^{\frac{1}{p+1}} & \text{, if } u \le 1/\alpha \\ \left(\frac{1}{2 - \alpha u}\right)^{\frac{1}{p+1}} & \text{, otherwise} \end{cases} \quad (11)$$

where p = Distribution index for SBX (non-negative).
$\alpha = 2 - \beta^{-(p+1)}$

$$\beta = 1 + \frac{2}{x^{(2)} - x^{(1)}} \min\left[\left(x^{(1)} - x^{l}\right), \left(x^{u} - x^{(2)}\right)\right]$$

and x^l, x^u = lower & upper bounds of variable.

It is assumed that $x^{(1)} < x^{(2)}$. This procedure allows a zero probability of creating any offspring solution outside the prescribed range [x^l, x^u]. A small value of p allows solutions for away from parents to be created as offspring solutions and a large value restricts only near– parent solutions to be created, as offspring solutions. The SBX operator is applied variable by variable and in all simulation results, p = 2 has been used.

3. The offspring solutions are then calculated as follows:

$$y^{(1)} = 0.5[(x^{(1)}+ x^{(2)}) - \bar{\beta}\, | x^{(2)} - x^{(1)}|], \quad (12)$$

$$y^{(2)} = 0.5[(x^{(1)}+ x^{(2)}) + \bar{\beta}\, | x^{(2)} - x^{(1)}|] \quad (13)$$

3.3.3. Mutation Operator

A polynomial probability distribution is used to create a solution y in the vicinity of parent solution x [19]. The following procedure is used where lower and upper bounds (x^l and x^u) are specified.

1. Create a random number u between 0 and 1.
2. Calculate the parameter $\bar{\delta}$ as follows:

$$\bar{\delta} = \begin{cases} \left[2u + (1-2u)(1-\delta)^{q+1}\right]^{\frac{1}{q+1}} - 1, & \text{if } u \le 0.5, \\ 1 - \left[2(1-u) + 2(u-0.5)(1-\delta)^{q+1}\right]^{\frac{1}{q+1}}, & \text{otherwise} \end{cases} \quad (14)$$

Where q = Distribution index for mutation (non negative).

$\delta = \min[(x - x^l), (x^u - x)]/ (x^u - x^l)$

This ensures that no solution would be created out side the range [(x^l, x^u).

3. Calculate the mutated child as follows:

$$y = x + \bar{\delta}\, \delta_{max}. \quad (15)$$

Where δ_{max} = maximum perturbance allowed in the parent solution = $x^u - x^l$.

In all simulation results, q = 100 has been used.

3.4. GA Parameters

Selecting GA parameters like population size (s_p), crossover probability (p_c), mutation probability (p_m), and number of generations (n_g) is very difficult due to many possible variations in the algorithm and objective function. A real parameter GA relies on random number generators for creating the population, crossover and mutation. A different random number seed produces different results.

As far as population size is considered, traditionally large numbers of population of solutions have been used to thoroughly explore complicated objective surfaces. The number of generations is something like termination criteria, which indicates how many times the trials (iterations) are to be made.

Crossover probability is used to find the probable number of solutions ($s_{p,}$ p_c) to be crossed over to produce an equal number of offspring solutions. In order to preserve some good solutions selected during reproduction operator, ((1-p_c). s_p) number of solutions are simply copied to the new population. This process helps in exploiting promising regions of objective space by combining information from promising solutions.

Mutation probability is used in finding the probable number of variables to be mutated (p_m x s_p×n). This process helps in exploring different areas of the objective space by randomly introducing changes, or mutations, in some of the variables.

Table 1: Data of Bomberger's metal stamping problem

Part No.,i	Demand, Z_i (Units/year)	Production rate, P_i (units/day)	Setup cost, c_{ri} ($/setup)	Setup time, t_i (hours)	Holding cost, c_{ci} ($/unityear)
1	24,000	30,000	15	1	0.00065
2	24,000	8,000	20	1	0.01775
3	48,000	9,500	30	2	0.01275
4	96,000	7,500	10	1	0.01000
5	4,800	2,000	110	4	0.27850
6	4,800	6,000	50	2	0.02675
7	1,440	2,400	310	8	0.15000
8	20,400	1,300	130	4	0.59000
9	20,400	2,000	200	6	0.09000
10	24,000	15,000	5	1	0.00400

The production was on a one shift (8 hour day) basis. Daily costs were based on a 240 day year.

4. Computational Results

To illustrate the proposed methodology, the practical example originally given by Bomberger [2] is considered. The basic data for this problem were developed from metal stamping data. Table 1 shows the Bomberger's problem with machine utilization ($\Sigma Z_i / P_i$) equal to 0.22 (22%). It is to be noted that in the real world, the decision makers should be faced with the uncertainty and fluctuation problems in estimating the inventory costs and in setting limit on total cost of inventory. Therefore, a decision maker may employ the concept of fuzzy demands with the membership functions to cope with variations in inventory costs and total cost before planning the production strategies (i.e., solving the ELSP). Besides 22% machine utilization, the levels of utilization of 44%, 50%, 60%, 66%, 70%, 80%, 88%, 92%, and 95% are also solved by the present formulations. The different machine utilizations are obtained in such a way that Z_i = a times Z_i given in table 1, where a = possible positive constant (2, 2.266, 2.719, 3, 3.173, 3.626, 4, 4.1703, 4.306). In all the problems with respect to different machine utilizations, the following maximum acceptable violations of c_{ri} and c_{ci} are assumed:

p_{cri} = 5, 5, 7.5, 2.5, 25, 12.5, 100, 25, 50, 1

p_{cci} = 0.0002, 0.004, 0.003, 0.0025, 0.07, 0.006, 0.03, 0.15, 0.02, 0.001.

Also, the values of fbp and their corresponding maximum acceptable violations with respect to different machine utilizations are assumed to be as given in table 3. Table 2 shows the comparison of results by the proposed fuzzy and crisp models of ELSP for different cases of Bomberger's problem with different machine utilizations. The total cost of the crisp solution increases as the utilization increases. The total cost of the corresponding fuzzy model solution also increases with respect to increase in utilization. It is to be noted that, the difference between the total cost of crisp and fuzzy models is as low as $14 for 88% utilization problem. This is owing to the fuzzy costs that the constraints could actually be more binding. The difference between total cost of crisp and fuzzy models is as high as $55.42 for 60% utilization problem.

Table 2: Comparison of crisp and fuzzy ELSP results

%Utili-zation	fbp ($/year)		T(days)		k_1		k_2		k_3		k_4		k_5		k_6		k_7		k_8		k_9		k_{10}		α of fuzzy models
	Cri	Fuz	Cri	Fuz	Cri	Fuz	Cri	Fuz	Cri	Fuz	Cri	Fuz	Cri	Fuz	Cri	Fuz	Cri	Fuz	Cri	Fuz	Cri	Fuz	Cri	Fuz	
22.06	4073.56	4025.43	47.29	43.16	7.04	8.14	1.56	1.74	1.60	1.74	0.75	0.83	2.06	2.23	4.48	5.01	8.60	9.41	0.77	0.84	2.42	2.66	1.64	1.81	0.9491
44.12	5633.65	5612.80	33.08	35.75	7.13	7.29	1.59	1.48	1.64	1.51	0.78	0.74	2.10	1.94	4.54	4.22	8.71	7.95	0.80	0.74	2.50	2.32	1.66	1.58	0.9839
50.00	5983.67	5935.04	32.21	32.89	7.00	9.99	1.53	1.50	1.58	1.82	0.76	0.91	2.03	2.12	4.38	5.16	8.40	9.58	0.78	0.71	2.43	2.38	1.06	1.55	0.9610
60.00	6493.50	6438.08	32.41	36.43	7.00	7.97	1.39	1.83	1.44	1.39	0.70	0.71	1.84	1.63	3.97	4.31	7.63	7.43	0.72	0.65	2.22	1.97	1.00	2.27	0.9619
66.18	6740.27	6698.85	34.47	36.48	7.00	8.01	1.24	1.31	1.29	1.40	0.63	0.66	1.65	1.58	3.54	4.49	7.00	7.21	0.65	0.59	2.00	1.72	1.30	2.16	0.9511
70.00	6951.11	6902.56	33.53	35.05	7.00	7.59	1.24	1.20	1.28	1.24	0.62	0.60	1.64	1.59	3.51	3.53	7.00	7.06	0.66	0.62	1.99	1.95	1.00	1.35	0.9974
80.00	7378.37	7336.75	35.79	39.10	7.00	8.86	1.04	1.46	1.08	1.14	0.51	0.48	1.43	1.25	3.00	3.21	7.00	7.13	0.58	0.49	1.72	1.49	1.00	1.89	0.9632
88.24	7628.41	7614.41	38.46	38.98	7.00	7.06	1.00	1.00	1.00	1.03	0.44	0.44	1.27	1.24	3.00	3.17	7.00	7.01	0.52	0.50	1.50	1.46	1.00	1.03	0.9855
92.00	7774.18	7733.20	39.49	43.37	7.00	7.49	1.00	1.45	1.00	1.13	0.40	0.27	1.20	1.27	3.00	3.21	7.00	7.17	0.50	0.48	1.39	1.21	1.00	1.46	0.8889
95.00	7891.07	7839.65	40.56	41.05	7.00	7.06	1.00	1.01	1.00	1.00	0.37	0.36	1.14	1.16	3.00	3.00	7.00	7.00	0.48	0.46	1.33	1.32	1.00	1.01	0.9669

Cri: Crisp result; Fuz: Fuzzy result by FGA

Table 3: Values of fbp & p_{fbp} for different machine utilizations

$\Sigma Z_i / P_i$	22%	44%	50%	60%	66%	70%	80%	88%	92%	95%
fbp($)	4000	5600	5900	6400	6650	6900	7300	7600	7600	7800
p_{fbp}($)	500	800	900	1000	1000	1000	1000	1000	1200	1200

Table 4: GA Parameters used in crisp and Fuzzy models

% utilization	Crossover probability (p_c)	Mutation probability (p_m)	Population size (s_p)	Number of generations (n_g)	Best generation and Run No.
22.06	0.92	0.045	100	150	148,16
50.00	0.955	0.025	20	250	231,8
60.00	0.98	0.045	20	250	249,7
66.18	0.96	0.05	20	250	239,27
75.00	0.945	0.065	20	250	246,22
80.00	0.96	0.075	20	220	220,5
88.24	0.905	0.05	110	250	244,20
92.00	0.93	0.05	20	250	245,12
95.00	0.89	0.05	110	240	233,24

Table 5 : Fuzzy ELSP solution costs at increasing utilization levels and comparison with other approaches.

	88%	92%	95%
Independent solution: IS	$7589	$7714	$7812
Khouja et.al [6]: BGA	$8782	$9746	$12018
Chatfield [12]: GLS	$7697	$7974	$9140
Crisp solution: RGA	$7628	$7774	$7891
Fuzzy Genetic Approach: FGA	$7614	$7733	$7839
FGA distance from IS: (FGA–IS) / IS	0.3294%	0.7907%	0.3456%

Table 5 shows the comparison of ELSP solution costs of Bomberger's stamping problem at higher utilization levels (88%, 92%, and 95%) with those of corresponding fuzzy models. For all these levels of utilization, the total costs by FGA on the average are 0.4885% above that of independent solution (IS). It definitely indicates that the perturbations of inventory costs and total cost should be taken into account for the ELSPs in making the decision more proper and optimal. The present formulation reveals its usefulness.

The real parameter GA was coded in C-language and a parametric study of GA is carried out in solving each of the crisp models. The study is carried out by varying different GA parameters, viz., crossover probability (p_c), mutation probability (p_m), population size (s_p), and number of generations (n_g). By this study, the best set of GA parameters which gives the minimum value of the objective function can be found. The same sets of GA parameters are used in solving the corresponding fuzzy models.

Now for the crisp problem with the % utilization of 88.24%, initially one parameter, viz., crossover probability is varied from 0.89 to 0.99, Keeping the other parameters fixed to the values of p_m = 0.01, s_p = 20 , and n_g =20. Then all the objective function values are compared, and the crossover probability corresponding to minimum value of objective function value is selected as the best p_c. It was found to be 0.905. The above study is then repeated for different values of mutation probability from 0.005 to 0.11 in steps of 0.005, keeping the other parameters fixed to the values of p_c = 0.905, s_p = 20, n_g = 20. Then the best mutation probability corresponding to minimum value of objective function was found to be 0.05. By keeping the parameters p_c = 0.905, p_m =0.05, ng =20, the population size is varied from 20 to 220 in steps of 10. The best population size was found to be 110. Finally the number of generations are varied from 20 to 250 in steps of 10, keeping the other parameters constant at p_c = 0.905, p_m = 0.05, s_p = 110. The best number of generations was found to be 250. Thus the best GA parameters after the study are: p_c =0.905, p_m = 0.05, s_p =110, ng =250. The results of parametric study, i.e., best GA parameters for different % utilizations are furnished in table 4.

5. Conclusions

This paper has addressed a useful formulation of ELSP under fuzzy environment. The ELSP in-turn was formulated via the BP approach with the cycle time T_i of each item modified and expressed as a real multiple k_i of a fundamental cycle T. This modified formulation along with the fuzzification of inventory costs and total cost is ideally suited for using real coded GA. It is noticed that the FGA produced good results as compared to the corresponding crisp results of all cases of the Bomberger's stamping problem. The total cost of crisp and fuzzy models is as low as $14 for 88% utilization problem and as high as $55.42 for 60% utilization problem (Table-2). Also FGA has given better results at higher utilization levels of the problem (88%, 92%, and 95%). For all these levels of utilization, the total costs by FGA on the average are 0.4885% above that of independent solution (Table-5). It showed that the perturbation of inventory costs and total cost should be taken into account in the ELSP by the use of proposed model. Future research may consider the fuzzification of other parameters, viz., demand and fundamental cycle time. The GA may also explore the solutions for other approaches of ELSP. Also in this paper, linear membership functions are only considered to represent the nature of variations of fuzzy variables. The membership functions like parabolic, exponential, hyperbolic, etc. can also be considered.

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Effect of Half Length Twisted-Tape Turbulators on Heat Transfer and Pressure Drop Characteristics inside a Double Pipe U-Bend Heat Exchanger

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Abstract

Influences of the half length twisted tape insertion on heat transfer and pressure drop characteristics in a U-bend double pipe heat exchanger have been studied experimentally. In the experiments, the swirling flow was introduced by using half-length twisted tape placed inside the inner test tube of the heat exchanger. The results obtained from the heat exchangers with twisted tape insert are compared with those without twisted tape i.e. Plain heat exchanger. The experimental results revealed that the increase in heat transfer rate of the twisted-tape inserts is found to be strongly influenced by tape-induced swirl or vortex motion. The heat transfer coefficient is found to increase by 40% with half-length twisted tape inserts when compared with plain heat exchanger. It was found that on the basis of equal mass flow rate, the heat transfer performance of half-length twisted tape is better than plain heat exchanger, and on the basis of unit pressure drop the heat transfer performance of smooth tube is better than half-length twisted tape. It is also observed that the thermal performance of Plain heat exchanger is better than half length twisted tape by 1.3-1.5 times.

Keywords: Heat transfer coefficients; heat transfer enhancement; heat exchanger; turbulences promoters; Twist tape.

Nomenclature

A	Area of heat transfer m^2
di	Inside tube diameter, m
d_0	Outside tube diameter, m
d_e	Equivalent Diameter $\{(D_i^2-d_o^2)/ d_0 \}$, m
Di	Inside diameter of annulus pipe, m
D_0	Outside diameter of annulus pipe, m
Y	Twist ratio =Half Pitch/tube diameter {P/di}
L	Length of tube
Δp	Pressure drop, kg/cm^2
M	Volume rate of flow, LPM
M	Mass flow rate, kg/sec
Q	Rate of heat transfer, W
C_p	Specific heat of fluid, KJ/kg-K
Th_i, Th_0	Inlet and outlet temperature of hot fluid, ^oC
Tc_i, Tc_0	Inlet and outlet temperature of cold fluid, ^oC
h_h	Inside heat transfer coefficient for oil, W/m2-k
h_c	Water side heat transfer coefficient for oil, W/m2-k
θ	Log mean temperature difference, K
Re	Reynolds No.
Pr	Prandt1 No.
N_u	Nusselt No.
K	Thermal conductivity of fluid, W/m-k
f	Friction factor
U	Overall heat transfer coefficient, W/m^2-k

Greek Symbols

α	Thermal diffusivity, m^2/sec
μ	Dynamic viscosity of fluid, N-sec/m^2
ρ	Density, kg/m^3
ν	Kinematic viscosity of fluid, m^2/sec

Subscripts

h	For hot fluid (oil)
c	For cold fluid (water)
i	Inlet
o	Outlet

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1. Introduction

Heat exchanger is the apparatus providing heat transfer between two or more fluids, and they can be classified according to the mode of flow of fluid or their construction methods. Heat exchangers with the convective heat transfer of fluid inside the tubes are frequently used in many engineering application. Enhancement of heat transfer intensity in all types of thermo technical apparatus is of great significance for industry. Beside the savings of primary energy, it also leads to a reduction in size and weight. Up to the present, several heat transfer enhancement techniques have been developed. Twisted-tape is one of the most important members of enhancement techniques, which employed extensively in heat exchangers.

A detailed survey of various techniques to augment convective heat transfer is given by Bergles [1].Twisted tape techniques have been used to augment heat transfer in double pipe heat exchanger. Kumar et al. [2] found that coiled type of swirl generator causes the increase of 72% in heat transfer, but frictional power also increases 90%. For water flowing through a vertical stainless steel tube, pitch to diameter ratio of 1.0 to 5.5 was used. Hong et al. [3] found that in the case of high Prandtl Number fluid in laminar flow, the heat transfer rate increases considerably for a moderate increase in pressure drop. Saha et al. [4] have considered twisted tape element connected by thin circular rods. They observed that the pressure drop associated with the full-length twisted tape could be reduced without impairing the heat transfer augmentation rates in certain situation. Smith Eiamsa-ard et al. [5] conducted experiments on a concentric tube heat exchanger. Hot air passed through inner tube while the cold water was flown through the annulus. A maximum percentage gain of 165% in heat transfer rate was obtained by using the helical insert in comparison with the plain tube.Saha et al. [6] investigated the use of turbulences promoters with short length Twist tape, and regularly spaced Twist tape element. They achieved better thermodynamics performance with short length Twist tape, and regularly spaced Twist tape element instead of full-length Twist tape while working with twisted tape. Saha et al. [7] have considered different types of strips. The strips are of longitudinal rectangular, square and crossed cross-section, full length and short length, as well as regularly spaced types. They observed that short length strips perform better than full-length strips. Friction factor reduces by 8-58% and Nusselt no reduces by 2- 40% for short length strips. For regularly spaced strips elements, Friction factor increases by 1-35% and Nusselt no increase by 15-75%.Smith et al. [8] compared three different heat transfer enhancement methods namely: Microfins, Twist tape, and High fins to that of smooth tube. They observed that the heat transfer coefficients are increased by approximately 46%, 87% and 113% on average compared to those of smooth tube, using respectively Twist tape, High fins, and Micro fins. They also observed that on average the pressure drop of Micro fins tube is 38% higher than those of smooth tube. High fins tube increases the pressure drop by 81% in comparison to smooth tube, and Twist tape increases the pressure drop by 148%. Heat transfer and pressure drop characteristics of laminar water flow through a circular tube with longitudinal inserts were experimentally studied by Hsieh et al. [9]. Testing was performed on tubes with square and rectangular as well as crossed longitudinal strip inserts with Aspect ratio AR=1 and 4. Solanki et al. [10] conducted experimental and theoretical studies of laminar forced convection in tubes with polygon inner cores. Ray et al. [11] investigated experimentally correlations of heat transfer and flow frictions in a square duct with twisted-tape insert.Sivashanmugam et al. [12] investigated experimentally the heat transfer and friction factor characteristics of circular tube fitted with Right-Left helical screw inserts of equal and unequal length of different twist ratio.Naphon [13] investigated heat transfer and the pressure drop characteristics in a horizontal double micro-fin tube with twisted tape inserts. An overview of hundred research works of enhancement heat transfer rate by using twisted tape was reported by Dewan et al. [14]. Anil Singh Yadav [15] investigated heat transfer and the pressure drop characteristics in a double pipe heat exchanger with full length twisted tape inserts.

The objective of this paper is to study heat transfer and pressure drop characteristics of the u bend double pipe heat exchanger with and without half length twisted tape insert. The effects of various relevant parameters on heat transfer characteristics and pressure drop are also investigated. New data gathered during this work for heat transfer and pressure drop characteristics for the u bend double pipe heat exchanger with half length twisted taped insert are proposed for practical applications.

2. Experimental Setup

Figures 1 and 2 show a schematic view of the experimental setup and a concentric double pipe heat exchanger fitted with a half length twisted tape. The set-up consists of:

1. An oil tank with heater of 0.64 m^3 capacity placed on floor.
2. An overhead water tank 0.5 m^3 capacity located at an elevation of 2.75 meters.
3. Double pipe u bend heat exchanger.
4. Measuring devices like Rotameter, temperature indicator, and pressure gauge.
5. Twisted tape.
6. Gear pump.

The oil tank is placed on the floor; and is provided with heating coil of variable input. The tank dimensions are 0.8 m x 0.8 m x 1 m. The tank is provided with PVC tube of 1.85 m long and 5cm diameter, which is connected to 1.5HP motor. The motor outlet is connected to the inlet of heat exchanger through pipe to circulate hot oil in ckt. This pipe is connected to inner tube of heat exchanger through flange coupling. This pipe is provided with different measuring devices like rotameter, temperature indicator, and pressure gauge. An overhead tank is a Sintex tank of 0.5 m^3 located at a height of 2.75 m from the floor. The flow rate of water is kept constant at the rate of 15 Lit/min. Test section is double pipe heat exchanger of u bend type as shown in Figure 1. The Heat Exchanger consists of 2 m lengths in each arm and 0.465 m length of u-bend section. The heat exchanger is made up of stainless steel tubes. The inner diameter of inner tube is 2.11cm, and outer diameter of inner tube is 2.5 cm. Inner diameter of annulus pipe is 5 cm. The two straight legs of inner tube are connected to U-bend section with the help of flange coupling. The test section was heavily insulated by asbestos rope insulation. Rotameter is used to measure the flow rate of oil in the inner tube. Rotameter is connected at inlet to inner pipe of heat exchanger. The range of rotameter is 0-50 Lit/minute. Two Burdon pressure gauges are used at inlet section and another at outlet section of hot oil. The range of Pressure gauge is 0-5 kg/cm^2. The difference in reading of inlet and outlet pressure gauge gives the pressure drop in heat exchanger. Four Digital Thermometers are used at inlet and outlet section of each hot and cold fluid.

In all experiments twisted tapes were made out of 0.8 mm thick stainless steel strip. The width of which was 1 mm less than the inside diameter of test section.

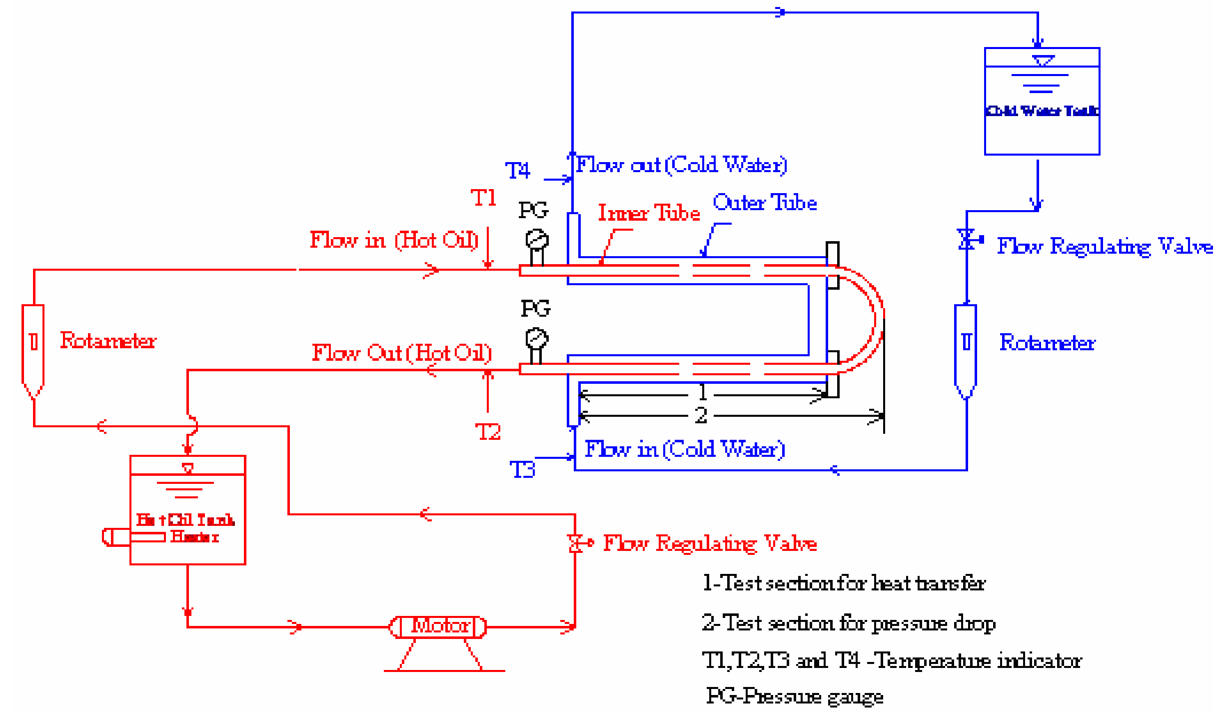

Figure 1: Schematic Diagrams of Experimental Setup.

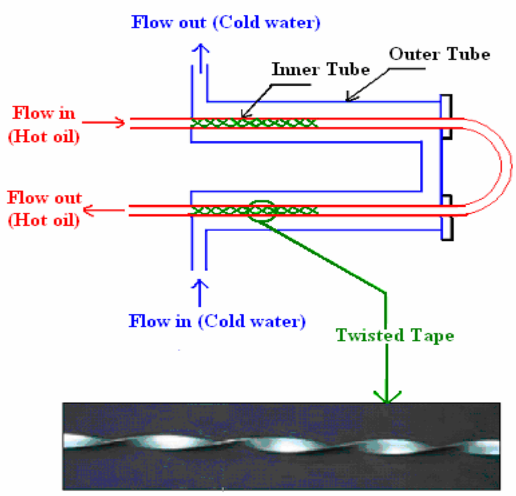

Figure 2: The inner tube fitted with half length twisted tape.

The strip were at first pushed into a tube, and then one end of the strip was tightened in a vice keeping tube in perpendicular position, and other end was twisted by tong. Twisted tapes were manufactured in the Amsler torsion-testing machine to the desired twist ratio; and were later inserted in the test section.

3. Experimental Procedure and Data Reduction

First the plain tube double pipe heat exchanger (i.e. without turbulator) was tested. At the beginning of series of tests, the hot oil was circulated through inner tube and cooling water through annulus tube in counter-flow configuration. The air was bled at various locations. The flow rate of water was fixed to 15 Lit./min. The cooling water coming in heat exchanger was at room temperature. First the oil flow rate was fixed to 2 Lit/min. A prescribed heat input was given to the oil in oil tank in sufficient state. Usually 1/2 hour was required for the attainment of steady state for a run. Once the steady state was reached the flow rates of hot and cold fluid, temperature reading at inlet and outlet section of hot and cold fluid and burden pressure gauge readings were taken. The flow rate of cold water was kept constant, and above procedure was repeated for different flow rates of hot fluid.

After completing the test with plain heat exchanger (i.e. without turbulator), the u bend double pipe heat exchanger was removed from loop. Then half-length twisted tape was inserted into the both straight legs (2m each) of the u-tube. The tape was inserted from one side and pulled from other end by thread or thin wire. Then the heat exchanger was connected in loop; and took various readings. Transformer oil was circulated inside tube and cold water through annulus in counter flow arrangement.

The range of values of various parameters considered in the present investigations is given in table 1.Heat input was determined from the enthalpy rise of the fluid. A linear variation in the bulk temperature was assumed over the test length. The tube wall inside temperature was calculated by one-dimensional conduction equation. The average wall temperature and the bulk mean temperature were combined with heat flux to give the Nusselt No. all the fluid properties were evaluated at the mean film temperature. Pressure drop data was obtained under isothermal condition, and the fanning fraction factor was calculated.

Table 1: Range/values of parameters.

Parameters	Range/values
The flow rate of oil (M_H) (Lit/min)	4, 8, 12,18,24,30
The flow rate of water (M_C)	15 Lit/min (Constant)
ID of inner tube (di)	0.0211 m
OD of inner tube(do)	0.025 m
ID of outer tube(Di)	0.05 m
The water temperature at inlet temperature)	25°C (ambient
Twist ratio for half length twisted tape	7
Thickness of Twisted tape	0.8mm
Length of Twisted tape	2m (2-piece)
Heat exchanger area(A_0)	0.628m^2
Test length of heat exchanger:	
For heat transfer	8m
For pressure drop	8.46m

4. Data Reduction Equations

The data reduction of the measured results is summarized in the following procedures:

For fluid flows in a concentric tube heat exchanger, the heat transfer rate of the hot fluid (oil) in the inner tube can be expressed as:

$$q_h = m_h c_h (T_{hi} - T_{ho})$$

Where m_h is the mass flow rate of hot oil, c_h is the specific heat of hot oil, T_{hi} and T_{ho} are the inlet and outlet hot oil temperatures, respectively.Heat transfer coefficient on hot oil side (h_h) can be calculated from

$$h_h = Nu_h \left({k_h}/{d_i} \right)$$

Where Nu_h is the Nusselt number for hot oil side and is given by:

1. For turbulent flow

$$Nu_h = 0.023 \ \mathrm{Re}_h^{0.8} \ \mathrm{Pr}_h^{0.4}$$

2. For laminar flow

$$Nu_h = 1.86 \left(\frac{d_i}{L} \mathrm{Pr}_h \ \mathrm{Re}_h \right)^{0.33} \left(\frac{\mu}{\mu_w} \right)^{0.14}$$

While the heat transfer rate of the cold fluid (water) in the annulus is

$$q_c = m_c c_c (T_{co} - T_{ci})$$

Where m_c is the mass flow rate of cold fluid, c_c is the specific heat of cold fluid, T_{ci} and T_{co} are the inlet and outlet cold fluid temperatures, respectively.Heat transfer coefficient on cold fluid (water) side (h_c) can be calculated from

$$h_c = Nu_c \left({k_c}/{d_e} \right)$$

Where Nu_c is the Nusselt number for cold fluid (water) side and is given by

1. For turbulent flow

$$Nu_c = 0.023 \ \mathrm{Re}_c^{0.8} \ \mathrm{Pr}_c^{0.4}$$

2. For laminar flow

$$Nu_c = 1.86 \left(\frac{d_e}{L} \mathrm{Pr}_c \ \mathrm{Re}_c \right)^{0.33} \left(\frac{\mu}{\mu_w} \right)^{0.14}$$

The overall heat transfer coefficient based on Outer surface (U_c) can be determined from

$$U_O = \frac{1}{\frac{1}{h_c} + \left(\frac{d_o}{k} \right) \ln \left(\frac{d_o}{d_i} \right) + \left(\frac{d_o}{d_i} \right) \left(\frac{1}{h_h} \right)}$$

Friction factor, *f*, can be calculated from

$$f = \frac{\Delta p}{\left({\rho u^2}/{2} \right) \left({L}/{D_i} \right)}$$

Where ΔP is the pressure drop across the test section, ρ is the density of oil, d_i is the inner diameter of tube, u is the velocity of oil, and L is the length of tube.

5. Result and Discussion

After having studied heat transfer and pressure characteristic, it becomes necessary to combine these to evaluate the performance of half-length tapes. For this purpose, their performance was studied, for each heat flux separately, for equal mass flow rates and unit pressure drop.

5.1. Equal Mass Flow Rate Basis

Figure 3 shows the performance evaluation for the half-length tapes on equal mass flow rates basis. This is a simple criterion for performance evaluation.

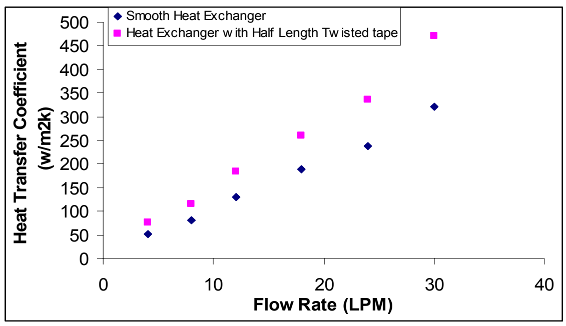

Figure 3: Flow rate vs. heat transfer coefficient.

Figure 3 shows that the average heat transfer coefficient inside tube increases with increase in the flow rate of fluid in each case. On comparing the different curves, it has been observed that heat transfer performance of half-length twisted tape is maximum followed by smooth tube. The heat transfer coefficient is increased by approximately 40% on average compared to those of smooth tubes using half-length twisted tape.

The increase in heat transfer coefficient from smooth tube to twisted tape can be well understood by boundary layer phenomenon. In smooth tubes, the flow is stream lined flow. Due to slip condition, the fluid in contact with tube (wetted perimeters) flow at very slow speed than inner core of tube. Due to this, boundary layer thickness is high, and heat transfer is retarded. The boundary layer thickness may be reduced by fitting turbulators to heat transfer surfaces. These twisted tape tabulators interrupt the fluid flow, so that a thick boundary layer cannot form.

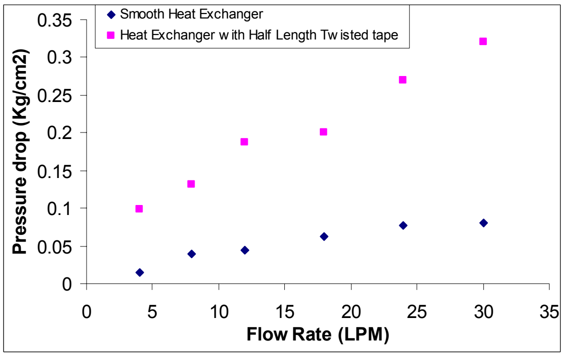

Figure 4: Pressure drop (ΔP) Vs. Flow rate.

5.2. Unit pressure drop basis

Unit pressure drop basis is an important criterion in heat exchange equipment design. An augmentative technique, which is effective from the heat transfer point of view, may fail in case it results in a pressure drop penalty greater than what the equipment can handle.

The increase in pressure drop is certainly a disadvantage resulting out of the use a turbulence promoter. The advantage gained in terms of increase of average heat transfer coefficient by using a turbulence promoter is partially offset by the increased pumping power requirements. In order to study the relative advantage of turbulence promoter vis-à-vis its disadvantage, the study of the parameter heat transfer coefficient per unit pressure drop appears to be appropriate. Figure 4 shows the plots of Pressure drop (ΔP) against Flow rate.

Figure 5 shows the plots of hi/ΔP against Flow rate. Thermal performance ratio of the heat exchanger is ratio of heat transfer coefficient to pressure drop. Thermal performance ratio = $h_i/\Delta P$ ($mk^{-1}s^{-1}$). On comparing the different curves of figure 5, it has been observed that Thermal performance ratio of smooth tube is maximum followed by half-length twisted tape. It has been observed that thermal performance of smooth tube is better than half length twisted tape by 1.0- 1.3 times. Thermal performance ratio decreases with use of turbulators because of increase in pressure drops more than increase in heat transfer coefficient.

6. Conclusion

From the present investigation on double pipe heat exchanger with and without twisted tapes inserts at different mass flow rate of oil, it was found that:

1. As compared to conventional heat exchanger, the augmented (with turbulator) heat exchanger has shown a significant improvement in heat transfer coefficient by 40% for half-length twisted tape.
2. On equal mass flow rate basis, the heat transfer performance of half-length twisted tape is maximum followed by smooth tube.
3. On unit pressure drop basis, the heat transfer performance of smooth tube is maximum followed by half-length twisted tape. It has been observed that thermal performance of smooth tube is better than half length twisted tape by 1.3-1.5 times.

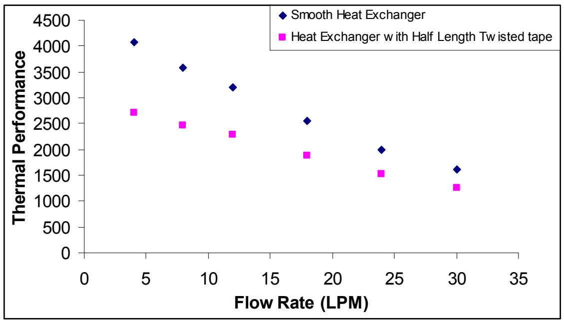

Figure 5: Flow rate Vs. Thermal Performance Ratio.

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An Intelligent Quality Function Deployment (IQFD) for Manufacturing Process Environment

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Abstract

This research work provides methodology for development of intelligent quality function deployment (IQFD) application in the manufacturing process environment. The paper is composed of the background of QFD, related research work review, and points for developing in manufacturing environment. Then, it describes the needs of development on intelligent QFD due to uncertainty on the available human experts in product development and expansion, so we overcome the lack of the human availability and achieving an expert environment that can predicate the quality of the assuming product with respect of customer demand, so that it can provide system for retrieving design and manufacturing data . The paper applied the proposed methodology on the case study of the air cooler manufacturing process. IQFD was developed in Microsoft Excel environment with the matlab R 2006 language.

Keywords: Quality function deployment; Voices of customer; neural network

1. Introduction

The quality function deployment is widely spreading into the world because of its outstanding usefulness. Basically, Quality Function Deployment (QFD) is aimed to fulfil customer's expectation of the product or service. QFD has been used by many companies because of the following three basic reasons (1) To save design time and development time (2) To focus on the satisfaction of customer (3) To improve communication at all levels of the organization.

Based on these three basic reasons, the research expansion of the traditional QFD can be analyzed into three branches. For the first reason, the QFD can be implemented effectively for developing the new product design by pointing the linkage between design stages through manufacturing environment. However, the traditional QFD is quite weak in implementing the modification of the existing product due to lack of human experts. In real application of QFD, the human experts are needed to provide the relationship on each matrix of QFD implementation. But, the life of the human expert, sometimes, could not last long enough with the product development. In addition, the human expert who is involved in the initial development of QFD might not stay long enough with the company. In those cases, the company that used QFD efficiently met the problem of the lacking of human experts or historical product design development. Therefore, it is necessary to keep track of the product development history to shorten the product and design development.

For the second reason, many researchers are currently focused on the development of many approaches, and some are known as 'voice of customers' [1-2] for prioritizing customer needs. At that point, Cohen [3] also stated in his QFD book that it is necessary to prioritize customer needs based on market analysis. He compared between prioritization matrix method and analytical hierarchy process method, and also provided advantages and disadvantages of each method. Despite its invaluable contribution to the field of product manufacturing and design, it does have its feebleness. First, QFD has neglected to take into consideration the priority among customer requirements.

Some customer attributes may be felt, or actually are, having greater or lower priority than others. QFD does not prioritize the attributes in any of its procedures. Consequently, inconsistency in the result would be inevitable. Fortunately, Saaty [4] has done a research in using Analytical Hierarchy Process (AHP) in prioritizing customer requirements in QFD. Second, conventional QFD procedures have embedded in itself a tendency for subjective valuation of the weight in the relational matrix of House of Quality (HOQ). This might cause bias in the outcome and vary the actual result.

For the third reason, QFD is well organized for improving the communication inside the organization if it is correctly implemented [1]. On the other hand, the improvement of the personal computer power and internet communication derive to develop computerized QFD [5] and decision support system of QFD [6]. Therefore, this research is focused on above three reasons and the implementation trends of QFD. It can be concluded that QFD needs to be computerized for better communication

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by using Internet facilities; the computerized QFD needs to possess the memory for remembering the past histories of the product development; QFD should be the decision support tool for making right decision.

Based on above conclusions, this research proposed to develop the intelligent QFD with the help of neural network (NN) facilities and implemented into the computerized environment.

2. Model Development

Basically, the QFD models can be classified into two categories: (1) four-matrix model and (2) matrix to matrix model (30 matrices) [7]. In this research, the four-matrix model is selected due to ease of implementation, and it suits for manufacturing environment. In product manufacturing, it can be analyzed as:

- The product matrix composed of the product attributes;
- The products components matrix
- The manufacturing processes matrix
- The production and control entities matrix

And the matrices details are shown in table 1.

For implementing QFD, it is necessary to have human experts for developing proper attributes, matrices, and links among developed matrices. For the new product development, it is not much difficult if all people tried to cooperate and shared information effectively. But, for modification of the existing product for meeting the changes of the customer's needs, the existing QFD will be met with difficulties of modifications and addition of new attributes or matrices because of lacking human persons who developed those QFD matrices initially. Therefore, it is necessary to keep in track the record of the changes and to map the expertise knowledge into the QFD development if possible. On the other hand, the NN research also developed very fast; and is efficient for mapping the human knowledge into computers. Thus, the research proposed to develop the IQFD by integrating traditional QFD and efficient mapping of the human knowledge into computers. Thus, the research proposed to develop the IQFD by integrating traditional QFD and NN technique. The framework of the model is shown in Figure1.

For implementation of QFD, a manufacturing environment for Air cooler production is selected. The prototype model initiated with generating customer expectations in the air cooler manufacturing. The model consists of four related matrices, which are product Part design Characteristics, Main product Components, manufacturing processes, and production and control entities as the last matrix. Each matrix is constructed in individual Excel worksheet.to capture the customer's needs effectively [1], we use the brainstorm group with interview to collect their needs.

2.1. Matrix I: Product Characteristics (Design Matrix)

This stage of QFD consists of the following information:

- Customer Requirements
  Product parts design characteristics
- The priorities of the customer requirements
- Relationship between the customer requirements and the product characteristics.

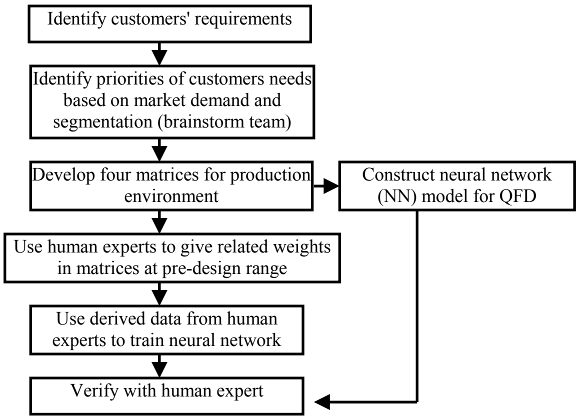

Figure 1 : the framework of IQFD model.

And the steps are:

1. The project did the market research for obtaining the customer requirements, and all the suggested customer requirements are listed out. They are related to the air cooler product characteristics in the matrix of HOQ, QFD's first and vital phase to product quality. The matrix of HOQ is shown in Table 2.
2. The team discussed the expertise available; and evaluated the priority of each requirement; numbers ranging from 9 to 1 are assigned to each requirement. Number 9 is assigned to the most preferable requirement, and the rest are assigned accordingly with decreasing preference. These priorities are shown in Table 1 as the importance column.
3. The product design characteristics that relate to those customer requirements are identified and placed along the top of the matrix. They are the product features of air cooler.
4. Then the impact of each product design characteristic on meeting those customers requirements based on the priority of requirement is quantified; and is so called the relationship values. The 9-point rating scale is used.
   9 = High impact on the requirement
   3 = medium
   1 = least impact
   The number in between indicates intermediate sense.
5. The importance or weight of each product design characteristics relating to the customer requirements is computed by summing the product between importance of customer requirement and the relationship value in the product design Characteristics matrix column. Matlab program facilitates the calculation in providing formulas to compute these weights. These values are shown in Table 1 as the Total row.
6. After the weights of product design Characteristics are computed. They are normalized by dividing them by the sum of all weights. They are shown as the Normalization row in Table 1.
7. Transferring the product design characteristics and their weights to the next matrix by placing the product design characteristics along the left of the next matrix and their weight next to it.

Table 1 : matrices contains.

Customer's requirements (CR)	Design requirements (DR)	Main and sub components	Processes and operations	Production and control attributes
Motor and water pump with long life	Size (a- small, b-medium, c-large).	Mechanical group (a- fan, b- fan cover, c- fan shaft, d-fan bushes).	Winding process.	Material entities.
Different size and shape	Shape (a- square, b- rectangular).	Electrical group (a- motor, b- water pump).	Coil finishing (varnish).	Electrical entities.
Low electricity consumption.	Weight (a- ordinary, b- medium, c- light).	Structure (a- frame, b- windows).	Manufacturing of motor body and water pump body.	Mechanical entities.
Quite and efficient working.	Brand name {the name of company} (a- acceptable, b- medium, c- very good).	Accessories (a- pulleys, b- belt, c- water distributor).	Manufacturing of shafts.	
Safety	Coil wire size.		Manufacturing of bushes.	
Light weight	Numbers of coil wire turns.		Join methods.	
Three fan speed	Assembly.		Plate cutting and forming.	
Low price	Rotating speed.		Manufacturing of accessories.	
Corrosion resistance	Warranty.			
	Durability (a- medium, b- high).			
	Manufacturing cost.			
	Power "electricity ".			
	Out put power "air ".			
	Metal type.			

Table 2 : Desigen Matrix.

CR/DR	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	important
1	0	0	0	0	0	2	2	2	3	5	9	7	7	4	8	9	5	7	7	7	5	4	6
2	8	8	8	8	8	3	3	3	3	4	6	3	3	5	3	3	3	3	7	4	6	5	2
3	5	4	6	0	0	2	2	2	3	5	7	8	8	2	8	5	4	6	3	8	7	3	3
4	2	2	2	2	2	2	3	3	3	5	7	4	4	6	7	6	6	7	7	4	5	7	7
5	0	0	0	0	0	0	0	0	2	5	7	4	4	5	4	6	4	5	7	4	2	7	1
6	3	5	8	0	0	6	5	9	1	3	5	0	0	0	0	2	2	5	5	1	3	8	5
7	1	2	3	0	0	0	0	0	2	5	8	7	7	2	8	3	2	3	7	8	8	3	4
8	3	5	7	2	5	2	5	7	2	5	9	1	1	2	3	5	5	7	9	3	3	9	9
9	0	0	0	0	0	0	0	2	2	5	8	0	0	0	1	8	5	7	8	0	0	8	8
Total	91	120	163	48	75	86	115	134	112	213	345	141	141	113	198	254	197	276	274	170	174	296	3440
Normalization%	2.84	3.48	4.73	1.39	2.18	2.50	3.34	3.89	3.25	6.19	10.02	4.09	4.09	3.28	5.75	7.38	5.72	8.02	7.96	4.94	5.05	8.60	

Table 3 : Componant Matrix.

CR/Components	A	B	C	D	E	F	G	H	I	J	K	Impo.
1	4	4	1	1	1	0	9	9	2	3	1	2.84
2	4	4	2	2	1	0	9	9	4	3	2	3.48
3	4	4	3	3	2	0	9	9	6	4	2	4.73
4	4	3	1	0	1	0	9	9	0	2	5	1.39
5	4	3	1	0	1	0	9	9	0	2	5	2.18
6	2	2	1	0	0	0	4	2	1	0	0	2.5
7	3	3	1	0	0	0	6	3	1	0	0	3.34
8	5	5	2	0	1	0	9	6	3	0	0	3.89
9	3	3	1	1	1	1	2	2	1	0	0	3.25
10	3	3	1	2	3	3	2	2	1	0	0	6.19
11	5	5	3	5	9	9	5	5	3	2	1	10.02
12	0	0	0	0	7	7	0	0	0	0	0	4.09
13	0	0	0	0	7	7	0	0	0	0	0	4.09
14	2	2	2	2	2	1	3	1	1	0	3	3.28
15	6	1	2	2	7	0	0	0	9	6	0	5.75
16	0	0	1	1	7	7	7	8	1	2	0	7.38
17	0	0	1	1	3	2	4	4	1	1	0	5.72
18	1	1	2	2	5	5	7	7	3	2	1	8.02
19	2	3	3	4	8	7	9	9	4	2	1	7.96
20	0	0	0	0	9	7	0	0	1	0	0	4.94
21	1	0	0	0	9	0	0	0	5	1	0	5.05
22	3	5	7	7	1	1	9	9	7	0	0	8.6
Total	205.42	234.17	211.70	220.22	610.22	373.04	663.37	487.70	310.00	160.41	72.57	3405.30
Normalization%	7.70	6.87	6.21	6.48	14.98	10.08	18.24	14.32	9.30	4.60	2.13	

2.2. Matrix II: Product Components (Components Matrix)

Air cooler component consists of two levels, main component at the first level, and sub component at the second level.1. The project team breaks down the main and sub components, and places them along the top of Matrix II. It aims to determine the degree of impact that the product design characteristics have on main/sub components. 2. Determine relationship values between main/sub components and the product design characteristics. They are shown in Table 3. 3. The weight of each component is given and normalized similarly as previous. Finally, transferring the components matrix into matrix III. This is manipulated automatically by matlab program with its built-in function.

2.3. Matrix III: Processes Matrix

This matrix relates the components to its manufacturing processes (Table 4). The procedures are as follows: 1. from the air cooler, the air cooler processes are arranged at the top of the matrix. The objective is to determine the interrelationship between the manufacturing processes of the components and the parts components. This helps to identify where emphasis is to be placed on. Soon processes will be related to production and control entities at the last matrix. 2. Quantify the relationship values for each process. 3. The weight of all processes components is automatically calculated by matlab and normalization is done. 4. Transfer the process components and their weights to the next matrix.

2.4. Matrix IV: Production and Control

The matrix is presented as Table 5.

1. Identify the production and control entities with respect to the process components and arrange them at the top of this matrix.
2. Quantify the relationship values.
3. Matlabl formula calculates the weight of each production and control entities and their normalization values.

At this stage, the corresponding importance of production and control entities is known, so the team can decide on which production and control entities to pay more attention. As a result, it will lead the manufacturing team to concentrate on the right way that significantly reduces the time wasted on guessing. After developing the QFD matrices for air cooler, it is necessary to receive the expertise ideas of giving weights in the relationship among matrices. At that point, the NN is developed based on the QFD matrices structure. The integrated QFD model is shown in figure 2.

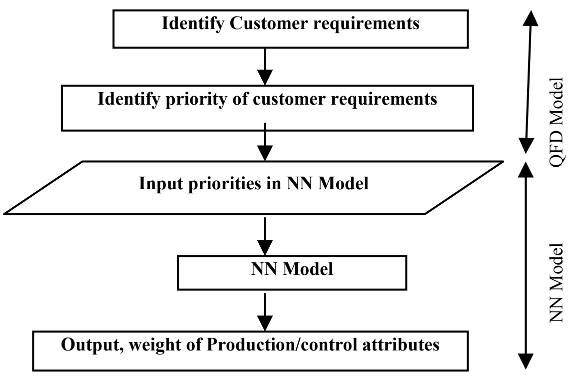

Figure 2: Integrated QFD model.

3. Neural Network Model Development

3.1. Constructing the Network

Conceptually, the network is constructed based on the input of customer requirements. Taking into account the priorities among the requisites, the network calculates within its inner layers of processing units; and generates the desired output as shown in Figure 3.

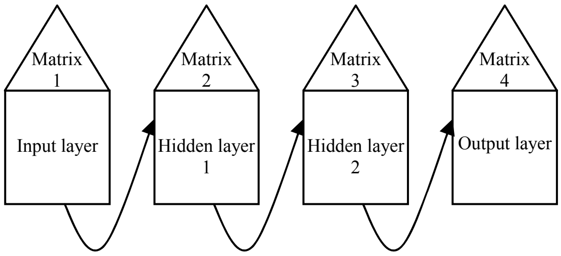

Figure 3 : Neural network construction with QFD.

Among the candidates of network architecture, the Multi-layer Perceptron (MLP) is chosen for its wide applicability and elementary structure. Then, assuming the simple nature of the problem, only one hidden layer is assigned to the MLP architecture. For simplicity and conformity to the 9-point rating scale, the end user needs are limited to only nine items. Relating to the number of customer requirements, the number of processing units (PE) is set to match the input channels of customer requirements. This will help to make the network to learn at the first trial, and thus reduce the number of training sessions required to produce a reliable network. The PE transfer function is of sigmoid curve. In more detail, a momentum type of learning rule is conducted throughout the training.

3.2. Generating Training Data Sets

The NN technique is used to overcome QFD weakness in subjective judgment of relationship values with the help of human expert. Initially, NN needs input of data sets to train the network. The training data sets are generated by QFD process in the following steps.

1. In the HOQ matrix, the priority for each customer requirements is assigned on a 9-point rating scale.
2. The relationship values between customer requirements and product design characteristics is quantified based on the priority of the customer requirements.
3. After entering the priority and relationship values into the matrix of HOQ, matlab automatically gives the production and control entities weights in the last matrix's bottom row. This is done by the inter-linking of the matrices in matlab.
4. Switching to a different set of priority, the corresponding relationship values yields another set of assembly attribute weights. By repeating the procedures, the training data sets for NN are generated. It is required that each customer requirement priority yields only one set of relationship values.

3.3. Training the Network

Before the network can be used, it must be trained sufficiently good to serve the forecasting purpose. Data sets are needed for training purpose.

Table 4 : Process Matrix.

Components / Processes	A	B	C	D	E	F	G	H	Impo.
1	0	0	0	2	2	5	9	0	7.79
2	0	0	0	0	0	7	9	0	6.87
3	0	0	0	9	8	6	9	4	6.21
4	0	0	0	8	9	6	9	0	6.48
5	9	9	9	0	0	0	1	0	14.98
6	9	9	9	0	0	0	2	0	10.98
7	0	0	0	0	0	6	9	0	16.24
8	0	0	0	0	0	7	9	0	14.32
9	0	0	1	3	0	1	5	9	9.36
10	0	0	0	0	0	0	0	9	4.59
11	0	0	0	0	0	2	0	9	2.13
Total	233.64	233.64	243	151.39	123.58	374.48	604.93	169.56	2134.22
Normalization %	10.94	10.94	11.38	7.09	5.79	17.54	28.34	7.94	

Table 5: Production and Control Matrix.

Processes/Prod.&Cont. At.	A	B	C	Impo.
1	2	9	0	10.94
2	1	9	0	10.94
3	1	9	1	11.38
4	7	0	9	7.09
5	7	0	9	5.79
6	8	0	9	17.54
7	9	1	9	28.34
8	0	0	4	7.94
Total	529.74	327.68	571.98	1429.4
Normalization%	37.06	22.92	40.01	

At that point, we used the plus minus two level design approach of relationship values of the first matrix to generate the training data sets. Then, 60% of the training data set is used for training the NN, and it checks the possible mean square error on each train. The training approach used 100 epochs. After training NN with 60 % of the generated data set, the remaining 40% data set is used for validation of NN. The training result in terms of mean square error can be seen in Figure 4 and Figure 5 and Fig.6. Then, the final weight values are obtained from the training section for the three layers of the neural networking units; and then embedded into the network simulation environment table5, table6 and table7. In conclusion, the trained NN for air cooler is working without the human expert, and it can generate the reasonable relationship by varying the customer needs' weights. Due to the NN structure solely dependent on the QFD matrix. And these weights are shown in table 6, table 7 and table 8.

4. Conclusions and Further Development

The proposed IQFD method is implemented in the computerized environment by using matlab 2006 and Neural Solutions Software.

Table 6 : final weight for first unit.

"Final weights of the synaptic connections for the three layers of the neural network in unit one"

```
v1= [   -1.4821  -0.8115  -0.4476  -0.9748   0.1549  -0.5914   0.3067  -0.4965  -0.1733;
        -0.2379   0.0508  -0.0075  -0.0384  -0.0224   0.1537  -0.0065   0.1622   0.0753;
        -0.0838  -0.0421  -0.0359  -0.0528   0.0058   0.0140  -0.1444   0.0626   0.0065;
         0.0257   0.0229  -0.2078   0.0055  -0.0425  -0.1863   0.0612   0.0092  -0.0293;
        -0.0184  -0.0959  -0.0144   0.1254  -0.0203  -0.0454  -0.1324  -0.0808   0.0083;
        -0.0168  -0.0146   0.1393  -0.2520  -0.1513  -0.0652  -0.0662  -0.0461   0.0766;
        -0.0117   0.0745   0.0652   0.0585  -0.1126   0.0103  -0.0146  -0.1406   0.2237;
         0.0168  -0.0890  -0.0377  -0.1008  -0.0815  -0.0221   0.0248  -0.0375   0.0327;
        -0.0501   0.0139  -0.0661   0.0944   0.0367  -0.0279  -0.0077  -0.0471   0.0863 ];
w1= [    1.3900   0.3770   0.0067   0.0679  -0.1921  -0.0256  -0.0111   0.0838  -0.0210;
         0.0555   0.0044   0.0997   0.0912   0.0541  -0.1499   0.0083   0.0795   0.0667;
         0.1002  -0.0314   0.1216  -0.0172   0.0932  -0.0050   0.1578  -0.0785  -0.1393 ];
Z1= [   -0.9935  -0.1351  -0.2680   ];
```

Table 7 final weight for second unit.

"Final weights of the synaptic connections for the three layers of the neural network in unit two"

```
v2= [    2.0012   0.3303   0.3458  -0.3488   0.4689   0.0415   0.0204  -0.0657   0.1217;
        -0.0673   0.0379  -0.0498  -0.0688   0.1736  -0.0447  -0.1228  -0.1003   0.0825;
        -0.0149  -0.0330  -0.1119   0.1339   0.1937   0.1082  -0.0670  -0.0186   0.0231;
        -0.2449  -0.0500   0.0808  -0.0909   0.1635   0.2373   0.1341  -0.1054   0.0672;
         0.0473  -0.0036   0.0041  -0.0413  -0.1256   0.0229   0.0388  -0.0072  -0.0508;
         0.0117  -0.0175  -0.0756  -0.0506  -0.0214  -0.0267   0.0393   0.0279   0.0856;
        -0.0591  -0.0957  -0.0089   0.1620  -0.0199   0.0702  -0.1707   0.1373   0.0269;
        -0.0655   0.1293  -0.2009   0.0081   0.0307  -0.0488   0.0228   0.0180   0.0625;
        -0.1081   0.0441   0.1084  -0.1081  -0.0572   0.1862   0.0686  -0.0542  -0.1047];
w2= [   -0.5607   0.0195   0.1321   0.1068  -0.0796   0.1416   0.4613   0.0860   0.2574;
         0.0434   0.1274   0.1320   0.1789  -0.0406  -0.1374   0.0756   0.1482  -0.1209;
        -0.1917   0.0639  -0.0909   0.0391  -0.1535  -0.0839   0.0376   0.0033  -0.0783];
Z2= [   -0.4135   0.0314  -0.4407];
```

Table 8: final weight for third unit.

"Final weights of the synaptic connections for the three layers of the neural network in unit three"

v3= [	1.7227	0.7087	0.2051	0.7215	-0.2017	0.2616	-0.1405	0.5181	-0.1038;
	-0.0277	0.0599	0.0580	0.0500	0.2690	0.1552	-0.0953	-0.0816	-0.0159;
	-0.1294	0.0147	0.0240	-0.0517	0.0290	0.1384	0.0778	0.2094	0.0871;
	-0.0888	-0.0101	-0.0351	-0.0559	-0.1423	-0.0758	-0.0006	0.0080	-0.0195;
	-0.0987	-0.2635	0.0892	-0.0753	0.0247	0.0443	0.0524	-0.0937	0.0075;
	-0.0072	0.0028	0.1578	0.0926	-0.1436	0.0911	0.1364	0.0636	-0.0527;
	-0.2415	-0.0876	-0.1108	-0.0249	0.0149	-0.1074	0.0482	0.1682	-0.0685;
	-0.0694	-0.0265	-0.0026	-0.0150	-0.1693	0.0202	-0.0787	0.0594	-0.0268;
	-0.1391	-0.0328	-0.1111	-0.1258	0.0719	0.0763	0.0752	0.0790	-0.1188];
w3= [	-1.4517	-0.3023	0.1727	0.1191	0.6450	0.2424	0.4894	0.2155	0.3843;
	0.0102	-0.0511	0.0179	0.0339	0.0599	-0.0335	-0.0953	-0.0579	0.0039;
	-0.0041	0.0249	-0.0037	-0.0131	-0.0086	-0.0322	0.0234	-0.0502	0.1541];
Z3= [	-1.0054	-0.1196	-0.1447	];					

Based on the case study of the air cooler manufacturing, Figure 7 , Figure 8 and Figure 9 show how the changing in the customers requirements at the first matrix effect the manufacturing trend at the last matrix focusing on three basic entities, which are the material , electrical and mechanical specifications. It is quite difficult to add the new customer needs or to reduce the customer needs after or during the manufacturing stage (through the layout operations which are basically a design conditions). The proposed method of IQFD allows the design to retrieve data systemization during the manufacturing processes and/or pre stage design, and the proposed method working well, and thus, the project is extending to handle adding, removing, and changing the attributes of design characteristics or the customer needs for neural network, which means very wide product specifications. In addition, it will be applicable for multi manufacturing domains and entering the sensitivity analysis to justify the possible changing relating to the weights of needs.

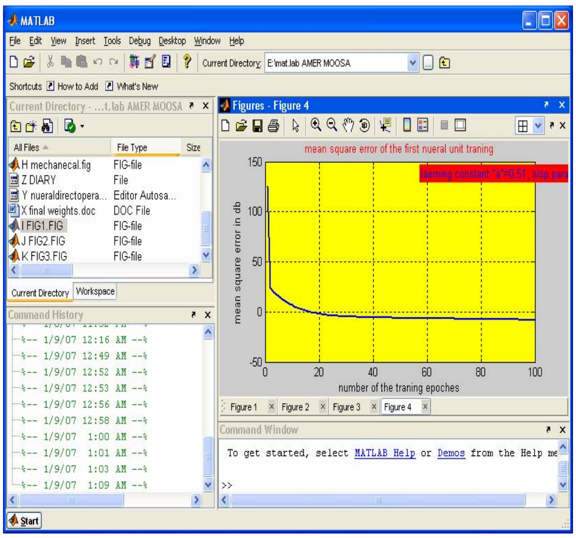

Figure 4: first unit error.

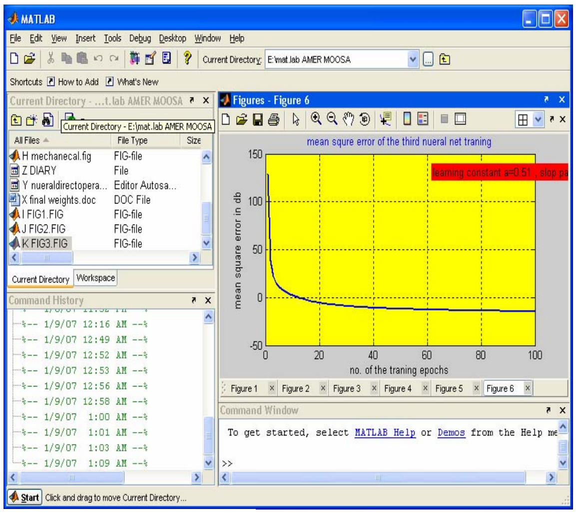

Figure 5: second unit error.

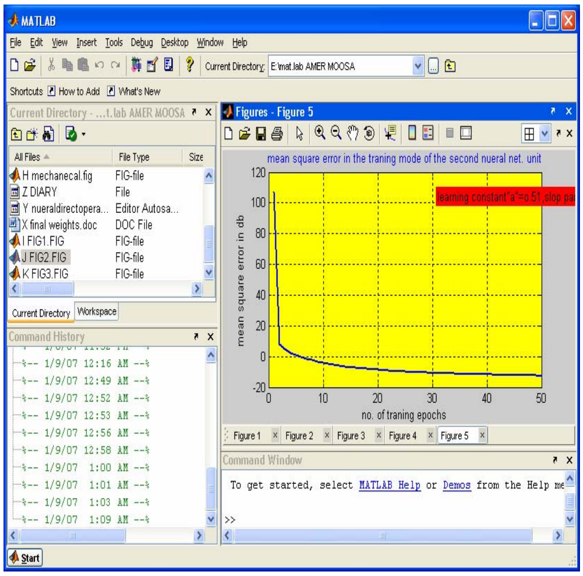

Figure 6: third unit error.

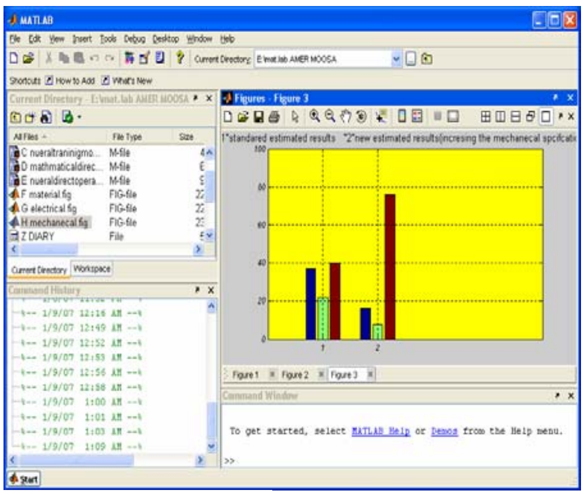

Figure 7: material properties.

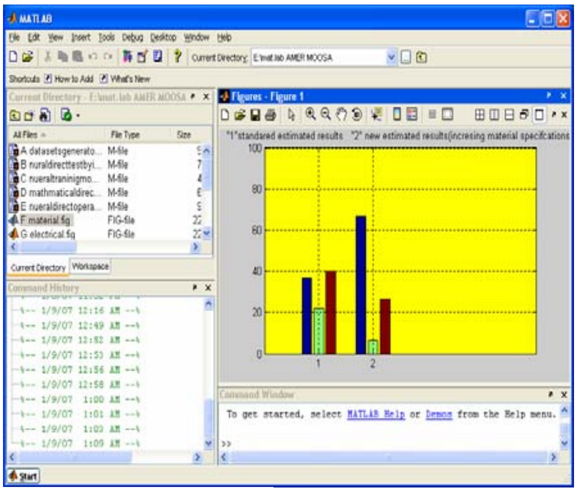

Figure 8 electrical properties.

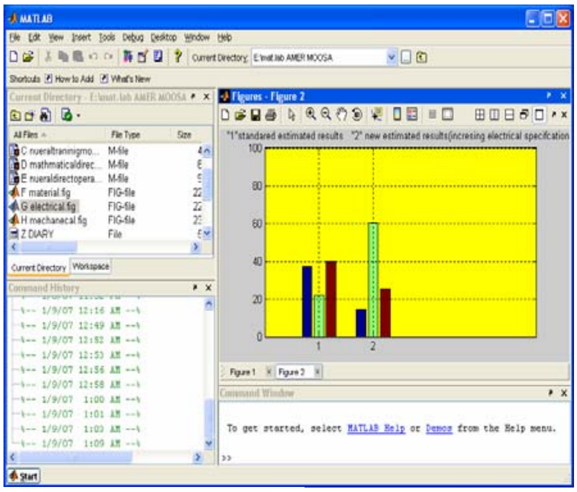

Figure 9 : mechanical properties.

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Statistical Modeling for Perception of Images in Stereoscopic Displays

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Abstract

Most of the training processes in the stereoscopic displays are performed within the virtual reality environment. Perception analysis of virtual space and operator interaction with the objects being in this space plays a special role when designing and realizing virtual reality systems. The analysis of human factors with further synthesis of the required characteristics will allow providing an optimal way in efficient application of technical capabilities of the complex of virtual reality operational systems and individual operator's peculiarities. In this paper, four main factors were studied to investigate their influence on the degree of efficiency of transfer and perception of information. The four main factors are: resolution, image form, operator's interaction, and control method. A fractional factorial design was utilized to build the experiment. The data was analyzed, and a statistical model explaining the effect(s) of different parameters as well as their interaction, was obtained. It was clear that the 3-D image with high resolution would increase the efficiency of information perception.

Keywords: Virtual reality system; Perception; Fractional factorial design

1. Introduction

There are two main characteristics that differentiate VR system from ordinary systems of computer graphics. First, beside simple transfer of visual information, the system simultaneously acts on several sense organs, namely, hearing, sense of touch, and even sense of smell. Second, VR systems provide direct contact of operator with the medium. The purpose of VR system is to place the participant in the medium which is not only natural, but also easy to study and to get to know. Virtual reality allows enlarging intellectual and communicative operator's abilities due to virtual medium that is generated by knowledge data bases from concrete objects into abstract ones.

The study of virtual reality systems allowed establishing different interaction levels, from limited in certain parameters to entire immersion into VR system. One of VR systems characteristics is preserving interactivity even with large set of data. This characteristic of VR systems provides possibility to interact directly with the real world of data i.e. to use the data sets themselves as objects echo in the cause of interaction
[1-3].

The main features of VR systems at present are considered to be the following; immersion, interactivity, and variability. The availability of these features is necessary and sufficient condition of technological system belonging to VR systems class.

Immersion means that the operator is immersed into virtual reality world, and he percepts himself and objects that he sees as a part of this world. There are three forms of immersion: direct, indirect, and mirror. When the participant feels himself as a part of the virtual world, he sees in the virtual world himself or a part of his body, or he sees the virtual world and himself in the mirror respectively [1].

Interactivity is operator's interaction with the objects of virtual reality world for the realization of functions stipulated by VR system program. Interactivity reveals in the form of: own movement in VR-world, interaction with VR world objects, and reaction (impact) of VR-objects on operator. Significant peculiarity of interactivity in VR-system is real time of its action [4-7].

Variability is necessary for improvement of VR systems efficiency in the sense of changing some values of the parameters that affect the output. Variability condition provides possibility to change features of VR worlds, scenarios, surroundings, game rules and etc., in accordance with the purpose of application of VR-system [8].

Future developments in immersive environments for mission planning include several tools which build up a system for performing and rehearsing missions. This system includes tools for planning long range sorties for highly autonomous rovers, tools for building three-dimensional (3D) models of the terrain being explored, and advanced tools for visualizing telemetry from remote spacecraft and Landers. In addition, Web-based tools for scientific collaboration in planning missions and

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performing public outreach and education are under development. These tools comprise a system for immersing the operator in the environment of another planet, body, or space to make the mission planning able to function more intuitively and effectively. The study provides the reader with the best settings of the factors effecting perception in the virtual reality operational systems (VORS). This will enables manufactures to use such settings that increase efficiency of various virtual reality (VR) tools.

2. Virtual Reality System

Depending on the problem, which the developers and users are facing, there are two types of virtual reality systems, namely operational and non-operational. Operational VR systems provide computer interface for specific perceptual and muscular systems for a definite purpose like training operator on the first medical responders [9]. The interface of the similar type allows operator to perform operations that would be impossible in common cases. Operational VR systems provide execution of concrete tasks facing the operator. The sense from the execution process is on the second place.

Non-operational VR systems are referred to VR-systems for entertainment, which is oriented towards out of use purposes as participation purposes. The experience in computer games development can lead to the creation of original non-operational VR-systems.

The interaction scheme of operator with VR system by means of effectors and sensors is considered. Virtual Reality system uses effectors such as; sound, odor, and temperature to stimulate receptors (sensors) of human perceptual system [4].

A display built in a helmet, a device of power feed back, like odor radiator can be used as VR effectors. VR system evaluates operator's activity expressed by the muscular system with the help of sensors. This scheme reacts on emotional response as well as stress states that can be reflected in operator's reactions. Taking into consideration the fact that man-machine interface allowing operator to interact with the modeled media in direct contact is the kernel of VROS system, let us consider its main modules; (i) Module for interaction with operator provides representation of medium state and registration of operator's actions performed with the help of effectors. (ii) Management module carries out analysis of actions made by the participant, determination of medium state changes in time and space and reaction formation on operator's actions. (iii) Module for interaction with the media forms changes of media state in real time. (iv)Module for media modeling provides realistic presentation of media; modeling of media, its objects and their behavior are also included here [10, 11].

Information knowledge base of VR system includes description of media, determination of time and space, relationship in it, as well as models of sensor-effectors systems of operator and system [8, 12]. At present, three types of realization of user's information interaction with VROS objects are considered.

The first type is in the fact of immersion into the virtual world. Operator wearing a space-suit provides with the information field "enters" digital Universe. Manipulating information glove, he has the possibility to interact with the computer touching and replacing objects of the virtual world represented on the display screen, "moves" or "flies" inside it with synchronous audio accompaniment.

The second type is presentation of three-dimensional space of the virtual world on the computer screen. The third type is interaction realization with virtual world objects by "the third person" represented by moving image on the computer screen and identifying with the user, where the user managers actions of "the third person" finding his own image on the display screen. Different forms of VR presentation suppose experimental research and development of recommendations on compensation of psycho-physiological limitations in virtual systems (of VROS type), efficiency improvement of virtual reality technology application. VROS analysis with regard to new technical solutions will allow increasing many times operator's abilities working in VROS [13].

3. Efficiency Criteria

Usually, efficiency of complex and large systems cannot be fully characterized by one single criterion; and is evaluated according to a number of criteria that are naturally much more difficult than system evaluation according to one criterion.

A number of conditions should be taken into consideration when selecting efficiency criterion:

1. Efficiency criterion should characterize not some part of the system nor its separate functions, but the system as a whole.
2. Efficiency criterion and its dependence on established factors should provide possibility of obtaining qualitative evaluation with the required accuracy and reliability.

At present two approaches, which define complex systems efficiency, are known:

- One index is selected from the set of system parameters, supposedly to be the most important. In this case the rest of indices have limitations. In terms of mathematics, the task is reduced to detecting of conditional extremism;
- Some generalized criterion is constructed on the basis of initial parameters set that characterized the system entirely. In this case, as a rule, all the parameters are considered in the system regardless of their values. The selection of the important parameters will be determined according to their influence on the constructed criterion [3].

The process of perception of visual information can be presented in a form of a function depending on a certain number N of factors:

$$Y_B = \sum_{j=1}^{N} \alpha_j E_j (x_1, x_2, \ldots, x_n), \tag{1}$$

Where E_j - influence of a concrete factor depending in general case on a number of variables, α_j - weight coefficient of the j -th factor.

Function Y_B describes the influence result of some set of factors with fixed levels of information perception; and is presented as a polynomial. The perception efficiency can be achieved by minimizing the difference between the quantity of presented information and the quantity of representing the same information. Then the criterion of information perception efficiency is

$$K_I = \min \{H_n - Y_B\}_T , \quad (2)$$

where

Y_B - quantity of represented information (in conditional units).

H_n - quantity of presented information (in conditional units), in which operator should interact within the scope of virtual environment.

All features of this environment including the form of objects, orientations, colors, and the scored points in case the operator was playing a 3D game are considered as presented information. And it is fully accessible for operator use without any limitation [3]. According to this fact, the quantity of presented information is considered to be 100%, and criterion of information perception is written in the following way:

$$K_I = \min \left\{ 1 - \sum_{i=1}^{m} \sum_{j=1}^{N} \beta_{ij} E_{ij} (x_1, x_2, \ldots x_n) \right\}, \quad (3)$$

where m – number of realizations between the four factors per each experiment. E_{ij} and β_{ij} should be determined experimentally.

Our target is to find out how the suitability of the VROS for practical and comfortable operator usage. This target can be achieved through the minimization of the difference between the quantity of certain information presented and represented to an operator.

To study the factors that affect the efficiency of perception for an operator through the VROS, some experiments should be conducted. Those experiments should be designed statistically in order to study all the factors effects and their interactions.

4. Experiment Design

VROS characteristics represented in Table 1 as factors influencing to the greatest degree on the efficiency of transfer, and perception of information are shown to have two level; high, and low.

The experiment was designed to find out how far the operator during his penetration within the virtual environment can be influenced by the selected factors in Table 1. The tool, which was used for testing operator's work, was the head mounted display (HMD) which was connected to the computer (PC). The PC has also a simulator of 3D and 2D game, which was fully designed to work with the VRS or HMD. The operator should spend 30 minutes using the VRS to achieve some progress during the 3D of virtual environment and the same time in the 2D of the same environment. Each VR environment had also different levels of complexity, like first level, which was the easier one, and the second level, which required more concentration. The used displays were represented by two different resolutions: Stereoscopic display that has 220x400 pixels and another display has 640x800 pixels resolution. The method control also was differing for the same period. The number of scores counted the overall output or the operator's progress, where each experiment was repeated 8 times. The four factors selected to be studied were chosen, because they were controllable and measurable, while other factors were inaccessible to be controlled or measured. Some of these factors are: the head-mounted angle, radiation of cathode ray tube and the weight of the HMD.

Table 1: Factors affecting perception rate and their levels.

FACTORS	**CODED LEVELS OF FACTORS x_i**	
	+1 (high)	-1 (low)
(A): x_1 - Image form on VROS	3D	2D
(B): x_2 - Resolution	640 × 800	220 × 400
(C): x_3 - OI Complexity level in VR-media	2	1
(D): x_4 -VROS control methods	VR Mouse + Special keyboard	Special keyboard

Where VR mouse -virtual mouse (manipulator), 3D- three dimensional stereoscopic image, 2D- two-dimensional flat image, resolution in pixels and complexity level of operator's interaction (OI) represents itself a number of objects preventing operator from fulfillment of set in VR tasks. The special keyboard used in this research experiment was a normal one with some buttons removed from its content. Thus, the research consisted in realization of multifactor experiment of "2^4" type (4 factors each of which varies on two levels). The experiment model will be written down in the form of the regression equation .(equation number 4)

Determination of the unknown coefficients of the equation can be made in the result of carrying out 16 experiments. In order to decrease the number of experiments, it is possible to neglect factors interactions of the high order, and to conduct a Fractional Factorial Design called fractional-factor experiment (FFD) wherein the number of experiments is reduced to 8 (half-fractional factorial design). The plan matrix of fractional-factor experiment is represented in Table 2. In Table 2, the negative sign is used for the lower level indication, and the positive sign is for the high level.

$$Y_B = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4 + b_{12}x_1x_2 + b_{13}x_1x_3 + b_{14}x_1x_4 + b_{23}x_2x_3 + \\ + b_{24}x_2x_4 + b_{34}x_3x_4 + b_{123}x_1x_2x_3 + b_{124}x_1x_2x_4 + b_{134}x_1x_3x_4 + \\ + b_{234}x_2x_3x_4 + b_{1234}x_1x_2x_3x_4 \quad \ldots\ldots\ldots\ldots\ldots (4)$$

Table 2: Parameter combinations used for the different experiments and their respective average perception.

Exper.Number	X_1	X_2	X_3	X_4	$\bar{y}_i$ (Perception)
1	-	-	-	-	34,58
2	+	-	-	+	70,00
3	-	+	-	+	50,00
4	+	+	-	-	96,50
5	-	-	+	+	34,48
6	+	-	+	-	81,10
7	-	+	+	-	60,00
8	+	+	+	+	93.08

5. Results and Discussion

The results, qualitatively, indicate the following general trends (i) efficiency increases when using 3D image; (ii) when using special keyboard, the efficiency will be better than using VR mouse -virtual mouse (manipulator); (iii) higher resolution will have a positive effect on the efficiency, but this effect is lower than in using the 3D image; and (iv) OI Complexity level in VR-media has the lowest impact on the response.

These experiments were performed and their outputs were analyzed. A statistical model presenting the relationship between the dependent variable (Efficiency) and the independent variables (the four factors) was obtained. Figure 1 shows the half-normal probability plot of the effects' estimates for the different combinations of the four factors used in the experiment. The half-normal probability plot is used here to determine the effect of each factor on the efficiency. The important effects that emerge from this analysis (indicated by their large distance from the straight line) are the image form (A), and the resolution (B). The IO complexity and the VORS method, however, do not have the same level of effect on the efficiency. The image form VROS in the model, also, appears to be the dominant factor in the efficiency model, followed by the resolution and the VROS method, and then by the IO complexity. Figure 1 and the statistical model do not show any interaction-effect to be dominant.

This statistical model (Figure 1) was tested against normality of its residuals, as shown in Figure 2; there was no indication for the presence of outliers. The analysis of variance for the model was also performed and the model was significant. The coefficient of determination was 99.8%, which indicates that about 99.8% of the variability could be explained by the model.

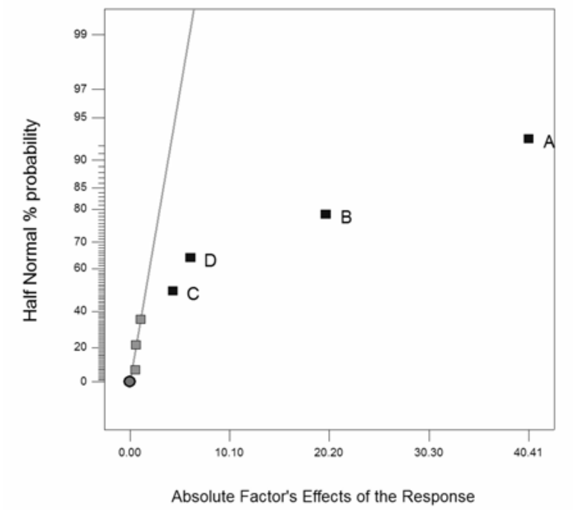

Figure 1: Effects of different factor on the efficiency.

Effeciency = +64.97 + 20.2*A + 9.936*B + 2.2*C - 3.3*D

This statistical model was tested against normality of its residuals, as shown in Figure 2; there was no indication for the presence of outliers. The analysis of variance for the model was also performed and the model was significant. The coefficient of determination was 99.8%, which indicates that about 99.8% of the variability could be explained by the model.

Confirmation tests were performed, and the error (difference between actual and predicted) was negligible. The analysis of variance (ANOVA) for the selected factorial model, Table 3, was significant with p-value < 0.0001, against F-value of 819.49. There is only a 0.01% chance that a "Model F-Value" this large could occur due to noise. Also it is evident from the ANOVA that all the model terms were significant. The model was also checked against any required transformation, and it was clear that no transformation is required. This is clear as shown in Figure 3. Lambda represents the power of transformation if it is needed for the model. The value of lambda for the power transformation is limited to the range of plus or minus 0.01 to 3.0. The Box Cox Diagnostic plot can help in determining the best lambda value to use.

6. Conclusions

he advantages of operators work in VR systems were proved theoretically and experimentally in comparison with the systems of information presentation in the flat image form.

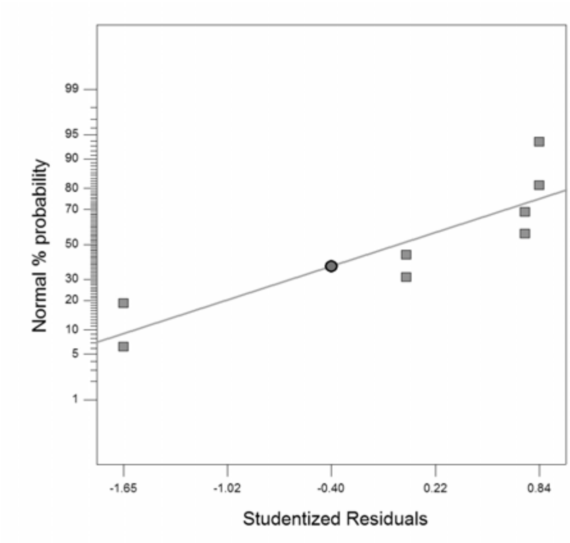

Figure 2: Normal Plot of Residuals.

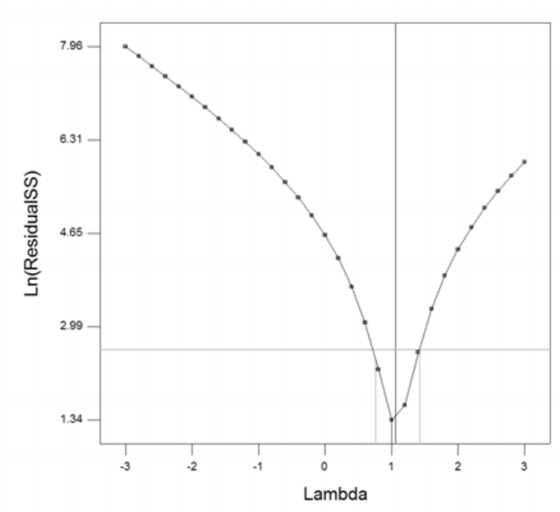

Figure 3: Box-Cox plot for Power transformation.

Table 3: Analysis of variance for the statistical model.

ANOVA for Selected Factorial Model					
	Sum of		Mean	F	
Source	Squares	DF	Squares	Value	Prob > F
Model	4167.97	4	1041.99	819.49	< 0.0001
A	3265.13	1	3265.13	2567.90	< 0.0001
B	788.44	1	788.44	620.08	0.0001
C	38.63	1	38.63	30.38	0.0118
D	75.77	1	75.77	59.59	0.0045
Residual	3.81	3	1.27		
Total	4171.78	7			

From the results obtained from the designed experiments, it is shown that it is better for the trainer to have a 3D flat image and to have a high resolution in order to get more perception and represented information. Also it is recommended to use the special keyboard instead of the virtual mouse for the VROS management method. Therefore, by performing the designed experiments for such system, it will help to understand the behavior and the performance of the factors that have influence on the response. This was achieved by obtaining the statistical model of the process.

7. Future Research

In this paper, the concentration was on the criterion of perception of information efficiency. There are many other criteria that can be visited and perform an optimization among the different criteria.

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Obstacle Avoidance and Travel Path Determination in Facility Location Planning

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Abstract

This research finds a solution methodology for determining optimal travel path to and from existing facilities and corresponding location of a new facility having physical flow interaction between them in different degrees translated into associated weights, in presence of barriers impeding the shortest flow-path involving straight-line distance metric. The proposed methodology considers all types of quadrilateral barriers or forbidden region configurations to generalize, to by-pass these obstacles, and adopts a scheme of searching through the vertices of these quadrilaterals to determine the alternative shortest flow-path for optimal location of facilities based on weighted-distance computation algorithm with minimum summation or mini-sum objective. Congruence testing has been carried out for reconfiguring complex obstacle geometry as an equivalent quadrilateral. This procedure of obstacle avoidance is completely new. Software, DANSORK, has been developed to facilitate computations for the new search algorithm and test results have been presented based on computations using this software.

Keywords: New Facility Location; Obstacle Avoidance; Quadrilateral Barrier Configuration; Computational Software

1. Introduction

The problems of locating a new manufacturing plant, or a distribution warehouse, and similar other facilities always involve the consideration of transport costs, which is dependent on the distance traveled for moving materials between such new facility and other existing facilities having logistic interactions such as; raw materials depot, feeder factory, or customer's warehouse. The distances between new facility and each of the existing facilities determine the optimal new facility location such that the total transportation cost is kept to minimum. The quantum and frequency of material movement load or the weight influences the considerations for fixing distances. Hence, optimality is dependent on weight, which is the product of the cost per unit distance of travel and frequency of trips per unit time period. The distance between facilities for material flow has been considered on the Euclidean distance metric with minimum summation or mini-sum objective. In many real life situations, the straight path for material flow between facilities is not available due to presence of forbidden regions or barriers such as; protected land, lake, another plant ,or any other physical obstacle creating constrained condition for movement. There has been sustained research interest in the area of facility location, which is reflected through the review of literature presented in the following paragraphs.

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Contreras and Diaz [1] considered Single Source Capacitated Facility Location Problem and proposed a Scatter Search approach. Also, a tabu search algorithm was applied. It has been observed that the method provides solutions with reasonable computational effort. Online Facility Location problem was dealt with by Fotakis [2], where the demand points arrive online, which must be assigned irrevocably to an open facility upon arrival. The objective is to minimize assignment costs. A multi-stage facility location problem, in the context of supply chain, formulated as a mixed integer program, has been presented by Wollenweber [3] where a two-phase heuristic solution approach was adopted. The greedy construction heuristic utilizes the solution obtained by the LP-relaxation of the problem. A study [4] addressed an evaluation of new heuristics solution procedures for the location of cross-docks and distribution centers in supply chain network design, where the model is characterized by multiple product families, a central manufacturing plant site, multiple cross-docking and distribution center sites, and retail outlets that demand multiple units of several commodities. A three-tier distribution network was examined [5]. It consists of a single supplier at a given location, a single intermediate warehouse whose location is to be determined, involving multiple retailers at given locations. Berman et al. [6] considered the problem of locating a set of facilities on a network to maximize the expected number of captured demand when customer demands are stochastic and congestion exists at facilities and propose heuristic-based solution procedures. A facility location problem in a continuous planar region considering the interaction between the facility and the existing demand points, and it has been dealt with by Karasakal and Nadirler [7] to maximize the weighted distance of the facility from the closest demand point as well as to minimize the service cost of the facility while the distance between the facility and the demand points was measured with the rectilinear metric. An interactive branch and bound algorithm were suggested to find the most preferred efficient solution. Four variations of the ant colony optimization meta-heuristic that explore different construction modeling choices were developed by Randall [8] in the context of capacitated hub location problem, and the results of the study reveal that the approaches can provide optimal solution in a reasonable amount of computational time. The work done by Dias et al. [9] describes a new multi-objective interactive algorithm and its ability to solve capacitated and uncapacitated multi-objective single, or multi-level dynamic location problems. The algorithm is part of an interactive procedure that asks the decision maker to define interesting search areas by establishing limits to the objective function values, or by indicating reference points. A new implementation of a widely used swap-based local search procedure for the p-median problem was presented by Resende and Werneck [10], and they have shown that their method can be adapted to handle the facility location problem and to implement related procedures like path-relinking and tabu search. Villegas et al. [11] modeled a bi-objective (cost-coverage) incapacitated facility location problem and designed and implemented three different algorithms that were able to obtain a good approximation of the Pareto frontier. The work of Farhan and Murray [12] developed general models that simultaneously address issues involving potential demand as a function of distance, coverage range, and partial regional service in facility siting. The developed models are general since they can be utilized for siting both desirable and undesirable facilities. Jia et al. [13] analyzed the characteristics of large-scale emergencies and proposed a general facility location model that is suited for large-scale emergencies where the general facility location model can be cast as a covering model, a *P*-median model or a *P*-center model, each suited for different needs in a large-scale emergency. Berman et *al.* [14] analyzed the problem of locating a set of service facilities on a network when the demand for service is stochastic and congestion may arise at the facilities while considering two potential sources of lost demand like increasing travel distance and long queues. They were investigated through several integer programming formulations and heuristic approaches in this context. A genetic-like algorithm was proposed by Pelegrín et al. [15] which is able to find a predetermined number of global optima, if they exist, for a variety of discrete location problems. Berman and Krass [16] examined the incapacitated facility location problem with a special structure of the objective function coefficients where for each customer the set of potential locations can be partitioned into subsets such that the objective function coefficients in each are identical. This structure exists in many applications, including the Maximum Cover Location Problem. Angelopoulos and Borodin [17] applied the priority algorithm framework to define “greedy-like” algorithms for the uncapacitated facility location problems and set cover problems. Drezner [18] solved gravity model for the competitive facility location problem and have shown that the generalized Weiszfeld procedure converges to a local maximum, or a saddle point while also devising a global optimization procedure that finds the optimal solution within a given accuracy. In a study Shaw [19] showed that several well-known facility location problems can be formulated uniformly into a special structured Tree Partitioning Problem; and also developed a generic algorithm to solve such facility location problems. In a study Berman and Drezner [20] investigated the problem of locating a given number of facilities on a network where demand generated at a node is distance dependent, and the facilities can serve no more than a given number of customers. Models proposed (Zhou and Liu, 2007) [21] for capacitated location–allocation problem with fuzzy demands, and several numerical experiments have been presented to illustrate the efficiency of some proposed algorithms.

It is evident from the aforementioned review that there are not many solution procedures for handling such location search problems involving barriers or forbidden areas in any number and shape which are present between facilities impeding straight path between them. However, in the recent past, the facility location problems involving barriers or forbidden regions have drawn the attention of the researchers in this area. Aneja, et al. [22] dealt with the barriers and forbidden regions based on network formation approach in location problems while Batta, et al. [23] proposed a solution with an approach of cell formation. Eckhardt, as mentioned by Katz et al. [24], dealt with some problems involving forbidden regions with polygonal configuration in which the paths are allowed through the forbidden region, but prohibiting the location of facility within the region. They studied the problem of single facility location involving Euclidean distance metric with mini-sum objective. Brady et al. [25] deployed interactive graphics to solve facility location problems with a minimax objective function involving single as well as multiple new facilities in presence of forbidden region having any arbitrary configuration. . Hamacher and Nickel [26] studied the location problem involving restrictions of forbidden region for developing the solution algorithms for median problems in the plane. Bypassing impenetrable barriers for placement of a single finite-size facility following rectilinear norm has been addressed by Savas et al. [27]. This interactive model considered identification of candidates for optimal placement for a facility with a fixed orientation, and then for a facility with a fixed server location and presented a heuristic. Optimal location of facilities in presence of impenetrable barriers following rectilinear metric has been attempted by Larson and Sadiq [28]. The new facility location for planar 1-median problem with convex polygonal forbidden regions has been addressed by McGarvey and Cavalier [29], and a solution procedure using the ’Big Square Small Square’ branch-and-bound is developed for global optimization. Most of the aforementioned studies consider either single forbidden region, or any specific shape of the restricted region. The objective of the present study, therefore, is to formulate a single facility location model amidst a host of existing facilities adhering Euclidean distance norm and restricted by single or multiple forbidden regions. The configuration of forbidden barriers in most of the studies is considered to be either rectangular or circular. The model presented in this paper is generalized in the sense that it considers the forbidden barriers in multiple numbers with arbitrary quadrilateral shapes including rectangle or irregular polygon to cover most of the applications using a single solution framework. A treatment is proposed here to reconfigure complex barrier geometry as an equivalent quadrilateral, and a congruence test has been carried out. In order to bypass the barrier contour and establish a flow route between facilities, a Cartesian grid element search method or cell formation or network formation approach wasdeployed earlier for exploring the alternative flow path. But such method is inefficient to handle multiple barriers of different geometries obstructing the flow path; and cannot be deployed correctly for determining the constrained shortest flow path. This research adopts a completely new approach in formulating the least-path search through the vertices of forbidden barriers and in developing an appropriate algorithmic computational methodology for a single facility location problem. Necessary generalization has also been made by way of considering the constraints with multiple barriers with arbitrary quadrilateral contour. The solution software,DANSORK, which has been developed[30] for determining the optimal location of a new facility under both constrained as well as unconstrained situations, will run on a simple PC.

2. Distance Computation Involving Quadrilateral Barriers

2.1. Distance Computation Involving Quadrilateral Barriers

The minimum distance between existing and new facility in presence of an quadrilateral obstacle as shown in Figure1 (A) & (B) has been either the path connecting the points (x_e, y_e) ; (x_2, y_2) ; (x_m, y_m) , that is through one vertex point of the barrier quadrilateral. Where the distance,

$$d_1 = [(x_e - x_2)^2 + (y_e - y_2)^2]^{1/2} + [(x_2 - x_m)^2 + (y_2 - y_m)^2]^{1/2} \quad (1)$$

Or, through the path, connecting the points (x_e, y_e); (x_4, y_4); (x_3, y_3); (x_m, y_m) , that is through two adjoining vertices of the barrier quadrilateral. Where the distance,

$$d_2 = [(x_e - x_4)^2 + (y_e - y_4)^2]^{1/2} + [(x_4 - x_3)^2 + (y_4 - y_3)^2]^{1/2} + [(x_3 - x_m)^2 + (y_3 - y_m)^2]^{1/2} \quad (2)$$

Minimum of d_1 or d_2 is the shortest path between an existing facility at a fixed and the new facility at any arbitrary location. Any of the two paths will be treated as shortest where $d_1 = d_2$.

To obviate the complexity in computation for the second case, that is, for computation of path length through two adjoining vertices of the barrier, a simplified distance computation procedure with a degree of approximation has been adopted, which will produce reasonably accurate results in practice. The distance in this case is the summation of two distance segments, namely, the distance from the respective existing facility to the nearest vertex of the obstructing quadrilateral and from the same vertex to the new facility located at any arbitrary point. This is the approximate substitution of the combination of three distance segments, namely, the distance of the existing facility from the nearest vertex of the obstructing quadruple, the distance of new facility from its nearest vertex and the distance between these two vertices. The justification is supported experimentally with three hundred problem samples. Most of the distance computations, as derived from the simulated experiment, are oriented with the involvement of single vertex of the barrier quadrilateral where the need of such approximation is absent altogether while in fewer other cases, the distance computations involve consideration of the adjoining vertices where the aforementioned approximation will be necessary. Thereby the overall effect of such approximation error is minimized, and in fact, is within one percentage as has been observed in the results of this experiment.

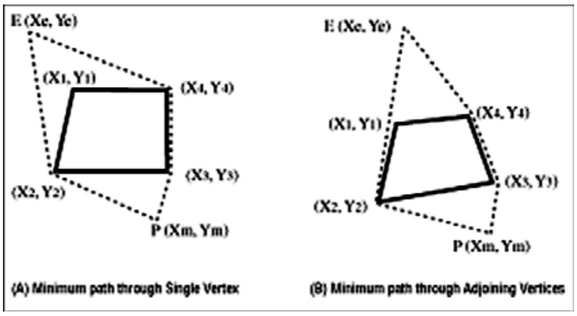

Figure 1: Least path Distance Search Scheme For Quacrilateral Barrier, a, b.

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2.2. Reconfiguration of a Complex Barrier as Equivalent Quadrilateral

The basic solution procedure involved in the analytical software based technique, as has been developed for the present research, does consider the forbidden regions or barriers having quadrilateral configuration only in a Euclidean space. Such quadrilaterals, of any form, can be immediately configured into the model without having to make any approximation in the geometry of the contour, unlike few other available techniques where only rectangular quadrilateral feature can be used without a contour approximation. Obviously, and also as reflected from the review of past research, such contour approximation is even more cumbersome, if possible at all, for other complex configurations such as geodesic, polygon, or composite shapes when present in a location analysis problem. However, since situations are encountered involving such complex forbidden configurations in many real-life facility location problems, an attempt has been made in the current research to develop some new techniques by which these complex or irregular obstacle configurations can also be accommodated into the location modeling framework while keeping the procedure still quite simple. In order to achieve this objective, the inter-facility distances have been simulated by transposition of an equivalent quadrilateral in substitution of the original complex configuration. A technique, with a simplistic approach, has been designed for deriving the configurationally equivalent quadrilaterals based on the parametric considerations as elaborated in the subsequent paragraphs.

The basic premise, that any uni-planar configuration will have extreme or boundary points along x-axis and y-axis in a Cartesian plane and eventually,

1. two such points, will be transfixed by x-axis; while
2. other two will be transfixed by y-axis.

Thus, such considerations and the corresponding treatment will give rise to four such extreme points in all. Hence, a quadrilateral will be formed by connecting these four strategic points which can be treated as an equivalent transposition, for example in the case of an inscribed square within a circle or within a polygon with the shape of a regular octagon. Another modality in framing the equivalent quadrilateral can be adopted by way of:

1. Projecting parallel lines to x-axis through the two extreme boundary points located on y-axis; and
2. Projecting parallel lines to y-axis through the two extreme boundary points located on x-axis.

Now, the extension of four such lines will produce four intersection points. A quadrilateral will be formed by connecting these four strategic points which can be treated as an equivalent transposition, like in the case of a circumscribed square on a circle or on a polygon with the shape of a regular octagon. However, while framing such equivalent quadrilaterals, extreme conditions may be generated where such configurations will be either completely inscribed in or circumscribed on the actual geometric contour as have been mentioned in the above cases, involving a geodesic (circular) and a polygon forbidden region. This can further be refined by moderating the construction technique for the equivalent configuration. This would be moderated as the mean of the above equivalent rectangular quadrilaterals, a square shaped in this particular case, for both the inscribed as well as circumscribed construction. This has been treated as the rationalized equivalent for all practical purposes. Such intermediate or moderated quadrilateral can be formed with the average or mean geometrical dimensions. Another rationalization modality can also be considered for construction, as has been adopted in the present casefor setting the equivalence. This has been done by selecting the mid points of a segment(s) parallel to any or both Cartesian axes as the one represented in Figure1C. Very often in such constructions, a part of the actual configuration remains outside the boundary of the equivalent quadrilateral where at the same time some portion of the actual contour is inside the contour of the equivalent configuration. The effect on distance computations due to such Transfiguration of obstacle geometries to equivalent quadrilateral shapes has been examined and presented in the congruence analysis section involving four extreme cases, as highlighted before, along with a moderated case as depicted in Figure1C. The combinational overall average error in distance computation has been found to be within 1% based on a simulated analysis carried out with randomly selected population of facility location coordinate points. The results of the analysis clearly demonstrate the correctness and suitability of the equivalence approach of transfiguring complex geometrical obstacles into the equivalent quadrilaterals.

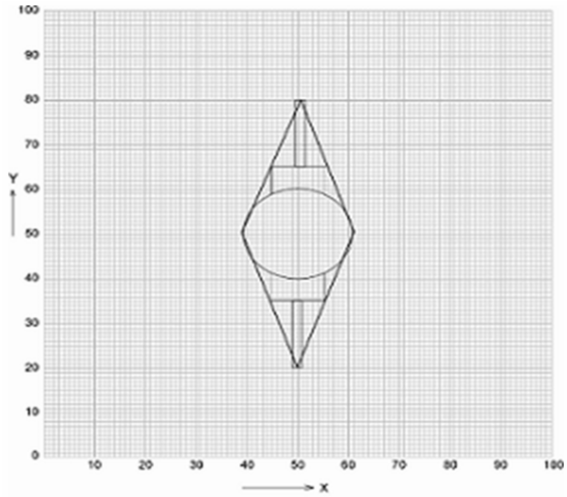

Figure 1c : Equivalent Quadrilateral for the Actual Configuration.

The validity testing for the degree of accuracy in distance computation between two points in presence of an equivalent quadrilateral, as a substitute for simulating the original complex configuration, has been analyzed and is presented in this section. This congruence testing is required to examine the practical usability of such transfigured equivalence. The procedural approach towards congruence analysis has been classified in two broad categories as follows based on the parametric treatment made on the actual geometric shape for transfiguration into an equivalent quadrilateral:

1. In the first category, the analysis has been carried out involving only extreme conditions where only completely inscribed or completely circumscribed equivalent quadrilaterals have been considered for a circular and a regular octagon. Whereas,

2. In the second category, detailed analysis has been carried out considering the composite type configuration as shown in Figure1C as a representative case.

It has been intended in the present set of analysis to determine the extent of deviation or error associated with such extreme cases because of the fact that if such errors are found to be within the acceptable limits for similar practical applications, then the usability of such techniques are far more cogent for the situation where the actual configuration is transposed with moderated equivalent quadrilaterals as depicted in Figure 1C. The actual obstacle configurations and the corresponding equivalents, based on already referred construction modalities, for both categories of equivalence, e.g., (i) extreme condition and (ii) moderated condition, have been elicited for the former and depicted in a graphical format for the latter for the dimensional and other related analysis where the problem space in question has been considered to be a planar matrix of hundred graphic units. The random number based location co-ordinate values have been expressed in graphical units for placing those in the matrix space while the forbidden configurations were transposed centrally for the congruence analysis as an example case has been presented in Figure 1C. The original complex geometry is depicted here with thin lines and the equivalent quadrilateral with thick lines in a 100 unit x 100 unit Cartesian grid space. The validity testing has been carried out to check the degree of accuracy in distance computation between two points in presence of an equivalent quadrilateral as a substitute for simulating the original complex configuration. This congruence testing is required to examine the practical usability of such transfigured equivalence.

The validity, or as may be called here as the congruence testing in the analysis of the above cases, has been carried out using a sizable three hundred (300) pairs of random number based co-ordinate values to represent the location points of the new and the existing facility.

The distance between the location points representing the facilities, in presence of forbidden configurations, has been either mathematically computed, or physically measured as was found appropriate in a particular quantification situation for onward comparison and also for determination of associated error. While the computation of the least path between two facilities through the single corner point of a quadrilateral shaped forbidden region has been relatively simple, an approximation technique with additional consideration of using a single vertex instead of two in distance computation as stated in the earlier section, had been necessary for the situations where the least intersection free path has been through two adjoining corner points of the forbidden quadrilateral. Based on this technique, a shorter-minimum path and a relatively longer path will be obtained. The summarized results and relevant comparative analysis in distance simulation with the extreme as well as the moderated equivalent quadrilateral construction for the corresponding true shape have been presented in TABLE-1 and TABLE-2 respectively. Orientation condition for congruence testing and analysis results for equivalent quadrilaterals simulating the actual forbidden configuration are based on the following structural pattern. The already referred selected configurations, e.g., the circle and the octagon, representing a geodesic and a polygon shape respectively, have been considered in the analysis of transposing extreme equivalent quadrilateral.

The select compositions for such analytical comparison are:

1. Inscribed and circumscribed quadrilateral within and on a circle separately; and
2. Inscribed and circumscribed quadrilateral within and on a polygon, a regular octagon here, in two separate sets.

The details of data analysis and deviation results for each individual set, as mentioned in the above sequential order, are presented in the TABLE – 1, and the case with the composite configuration and its equivalent quadrilateral are presented in TABLE-2. The solution procedure, here, does consider the barrier only with quadrilateral configuration. However, since many real-life barriers have rather complex configuration, attempt has been made in this paper to simplify the shape to fit in a modified or equivalent quadrilateral. It has been worked out in this fashion, so that other barrier shapes can also be included with some approximations in the solution format proposed here. The congruence or validity testing of such approach has been carried out. The effect of distance computations due to such transfiguration of complex obstacle geometry to equivalent quadrilateral shape has been analyzed with a sample case as shown in Figure1C. Random number based coordinate values, representing facility locations, have been expressed in grid-units for placing those in the Cartesian space while the barrier configurations were transposed centrally for the congruence analysis. The congruence testing has been carried out using a sizable three hundred (300) pairs of coordinate values generated based on random numbers to represent the location points of the new and the starting location facility through each such pair. The distance between each such pair of points representing facilities, bypassing the barrier configuration, has been computed analytically for comparison and to determine the error. The relevant analysis and summarized results in distance simulation with equivalent quadrilateral construction for the corresponding original shape have been presented in TABLE-2, which shows the ‘overall average percentage of error’ is to the tune of 0.25%. Such approximation yielding very low error is acceptable within practical limits, and hence has been accommodated in the current solution model.

3. A New Method for Distance Computation on Successive Identification of Barriers

3.1. Identification of Obstructive Quadrilateral

In order to establish a relationship between an existing facility and the corresponding obstructive quadrilateral, impeding a straight path to new facility, a mathematical identification of the particular barrier is necessary for iterative computation through computerized software. If a quadrilateral poses an obstruction on the straight line formed by joining the new and an existing facility, then logically the line has to intercept at least on two arms of that polygon.

Table 1 : AVERAGE VALUES AND FREQUENCIES (For Actual vis-à-vis Equivalent Configuration).

(1)	………………….(2)…………………. .	(3)	(4)	(5)	(6)	(7)	…(8)
1	Total test population of randomized strategic coordinate point sets(pairs) representing new facility and starting location facility	300	300	300	300	300	
2	Reference(Equivalent) configuration of 'Barrier'	I.S	C.S	I.S	C.S		
3	Frequency of occasions – the reference configuration posing obstruction on the straight line joining the pair of strategic points	66	83	45	70	66	45 - 83
4	Frequency of occurrence – the minimum distance is through single corner point(vertex) of the equivalent quadrilateral.	56	68	38	60	56	38 – 68
	(a) Average percentage of error in computing minimum distance through single corner point of the equivalent quadrilateral vis-à-vis the actual configuration.	0.53%	2.57%	0.76%	1.20%	1.27%	0.53%-2.57%
	(b) Largest percentage of error in computing minimum distance through single corner point of the equivalent quadrilateral vis-à-vis the actual configuration.	1.86%	11.17%	3.73%	5.03%	5.45%	1.86%-11.17%
5	Frequency of occurrence – the minimum distance is through adjoining two corner points(vertex) of the equivalent quadrilateral.	10	15	7	10	10.5	7 – 15
	(a) Average percentage of error in computing minimum distance through adjoining two corner points of the equivalent quadrilateral vis-à-vis the actual configuration.	3.93%	2.29%	1.68%	1.30%	2.3%	1.30%-3.93%
	(b) Largest percentage of error in computing minimum distance through adjoining two corner points of the equivalent quadrilateral vis-à-vis the actual configuration	14.88%	9.67%	3.25%	7.0%	8.7%	3.25%-14.88%
6	Grand average percentage of error in computing minimum distance through both the single and double point(s) oriented situations.	1.05%	2.52%	0.90%	1.21%	1.42%	0.90%-2.52%
7	Frequency of occurrence that the straight path connecting two strategic points are obstructed by the original obstacle configuration only and not by the superimposed equivalent quadrilateral.	5	-	15	-	5	NIL-15
	- Average percentage of error where the actual configuration poses obstruction only while the overlapping equivalent quadrilateral does not.	0.24%	-	0.29%	-	0.13%	NIL-0.29%
8	Frequency of occasions – the equivalent quadrilateral does not pose obstruction on the straight line segment connecting two strategic points including the cases where one or both strategic point(s) lie within the configuration(s)	229	217	240	230	229	217 – 240
9	Overall average percentage of error considering entire test population of strategic coordinate point sets.	0.23%	0.70%	0.14%	0.28%	0.34%	0.14%-0.70%

*Column No.(1): Serial Number.
*Column No.(2): Criterial Features.
*Column No.(3): Circular Configuration Vs. Inscribed Equivalent Quadrilateral.
*Column No.(4): Circular Configuration Vs. Circumscribed Equivalent Quadrilateral.
*Column No.(5): Regular Octagon (Polygon) Configuration Vs. Inscribed Equivalent Quadrilateral.
*Column No.(6): Regular Octagon (Polygon) Configuration Vs. Circumscribed Equivalent Quadrilateral.
*Column No.(7): Combinatorial Average Values.
*Column No.(8): Combinatorial Range of Values.

Table 2: AVERAGE VALUES AND FREQUENCIES (For Actual vis-à-vis Equivalent Configurations).

SL.No.	Criterial Feature	Values
1	Total test population of randomized strategic coordinate point sets(pairs) representing new facility and starting location facility	300
2	Reference(Equivalent) configuration of 'Barrier'	Superimposed overlapping quadrilateral
3	Frequency of occasions – the reference configuration posing obstruction on the straight line joining the pair of strategic points.	97
4	Frequency of occurrence – the minimum distance is through single corner point(vertex) of the equivalent quadrilateral. (a) Average percentage of error in computing minimum distance through single corner point of the equivalent quadrilateral vis-à-vis the actual configuration. (b) Largest percentage of error in computing minimum distance through single corner point of the equivalent quadrilateral vis-à-vis the actual configuration.	90 0.58 % 2.20 %
5	Frequency of occurrence – the minimum distance is through adjoining two corner points(vertex) of the equivalent quadrilateral. (a) Average percentage of error in computing minimum distance through adjoining two corner points of the equivalent quadrilateral vis-à-vis the actual configuration. (b) Largest percentage of error in computing minimum distance through adjoining two corner points of the equivalent quadrilateral vis-à-vis the actual configuration.	7 3.36 % 11.45 %
6	Grand average percentage of error in computing minimum distance through both the single and double point(s) oriented situations.	0.78 %
7	Frequency of occurrence that the straight path connecting two strategic points are obstructed by the original obstacle configuration only and not by the superimposed equivalent quadrilateral. Average percentage of error where the actual configuration poses obstruction only while the overlapping equivalent quadrilateral does not.	3 0.06 %
8	Frequency of occasions – the equivalent quadrilateral does not pose obstruction on the straight line segment connecting two strategic points including the cases where one or both strategic point(s) lie within the select configuration(s)	200
9	Overall average percentage of error considering entire test population of strategic coordinate point sets.	0.25 %

It is imperative to check mathematically as to whether the intercepting intersection points are on and within the polygon arm segment. The polygon would be treated as an obstacle if more than one such intersection points are obtained for any particular polygon. The mathematical equation of a polygon arm can be expressed in the general form as;

$$ax + by + c = 0 \qquad (3)$$

Where, x and y are cardinal variables; and a ,b ,c are coefficients. Such coefficient values [a; b; c] for each arm of a particular polygon connecting two vertices (x_s,y_s) and (x_t, y_t) would be given by:

$$[(y_t - y_s)/(x_t - x_s) \; ; \; -1 \; ; \; y_s - (y_t - y_s)/(x_t - x_s) * x_s]$$

Similarly, the coefficients [a' ; b' ; c'] for the line equation joining new facility location point (x_m, y_m) and each of the existing facility location point (x_e ,y_e) would be given by:

$$[(y_m - y_e)/(x_m - x_e); \; -1 \; ; \; y_e - (y_m - y_e)/(x_m - x_e) * x_e]$$

The coefficients of line equations for each arm of all polygons as well as of lines joining the new facility and each of the existing facilities are computed using developed software. The aforementioned intersection points, x_{int} and y_{int} are derived as follows:

$$[x_{int} \; ; \; y_{int}] = [(c' - c)/(a - a') \; ; \; (c'a - a'c)/(a - a')] \qquad (4)$$

Subject to the following sets of conditions :

$(x_s \square x_{int} \square x_t)$ or $(x_s < x_{int} < x_t)$; while, $[y_{s(\text{ or } t)} \square y_{int} \square y_{t(\text{ or } s)}]$ or $[y_{s(\text{ or } t)} < y_{int} < y_{t(\text{ or } s)}]$ and

$(x_e \square x_{int} \square x_m)$ or $(x_e < x_{int} < x_m)$; while, $[y_{e(\text{ or } m)} \square y_{int} \square y_{m(\text{ or } e)}]$ or $[y_{e(\text{ or } m)} < y_{int} < y_{m(\text{ or } e)}]$

A polygon would be treated as obstacle for the particular existing facility provided that the above conditions are satisfied together. This procedure is repeated successively for all obstacles for every existing facility .The next step is to compute the minimum distance bypassing the polygon, in case the same has been identified as an obstacle; and is presented in the following section.

3.2. A Methodology for Computation of Minimum Distance in Presence of Obstacle

Lines joining new facility and all the four vertex points of the particular obstructive polygon would generate equations of two lines, those are tangent to the polygon at two vertices and two other lines intersect the polygon. The subsequent computational step is to identify a couple of tangent vertices out of all four in a polygon. This is accomplished by following similar procedure adopted for identification of obstacles. Here, the coefficients [a" ; b" ; c"] of a line equation joining a vertex (x_s, y_s) of the obstructive polygon and the new facility point(x_m, y_m) is given by,

$$[(y_m - y_s)/(x_m - x_s) ; -1 ; y_s - (y_m - y_s)/(x_m - x_s)*x_s]$$

And the intersection point produced by this line with one of the polygon arms would be given by:

$$[x_{int'} ; y_{int'}] = [(c'' - c)/(a - a'') ; (c''a - a''c)/(a - a'')] \qquad (5)$$

Subject to**;**

$(x_s \square x_{int'} \square x_t)$ or $(x_s < x_{int'} < x_t)$,while,

$[y_{s(\text{ or } t)} \square y_{int'} \square y_{t(\text{ or } s)}]$or $[y_{s(\text{ or } t)} < y_{int'} < y_{t(\text{ or } t)}]$

Where, s and t are the terminal points of the line. Any line joining one of the vertices and the new facility would intersect one of the arms of the polygon, in the case that the particular vertex is not a tangent vertex. Mathematically, in such case, the number of intersections computed would be three including two occasions where it is on the same point at the vertex which is the common point lying on two intersecting arms of the polygon. This common point, mathematically, is counted twice and therefore, in the case of a tangent,the number of such intersections is two. A counter for computed number of such intersections has been provided in this software. Now, by connecting the two tangent points of polygon to location point of the specific existing facility, two separate paths with computed distances following the approximation technique as referred in section (2), are obtained and a minimum of these is selected. The mathematical expression of minimum distance through the corresponding polygon vertex points (x_{sk}, y_{sk}), of the j^{th} obstacle at the k^{th} vertex, from the new facility point (x_m, y_m) to the existing i^{th} facility point (x_{ei}, y_{ei}) is given as below :

$$\text{Distance} = [(x_{jk} - x_m)^2 + (y_{jk} - y_m)^2]^{1/2} + [(x_{jk} - x_{ei})^2 + (y_{jk} - y_{ei})^2]^{1/2} \qquad (6)$$

The summation of the products of the distances for both constrained and unconstrained situations and relative weight(w_i) associated with each existing facility is the total cost (C) burden for the particular location of the new facility which can be mathematically expressed as :

$$C = \square w_i\{[(x_{jk} - x_m)^2 + (y_{jk} - y_m)^2]^{1/2} + [(x_{jk} - x_{ei})^2 + (y_{jk} - y_{ei})^2]^{1/2}\} + \square w_i[(x_m - x_{ei})^2 + (y_m - y_{ei})^2]^{1/2} \quad \ldots\ldots\ldots\ldots\ldots\ldots(7)$$

Constrained, unconstrained .

The constrained condition arises in presence of barriers while in absence of barriers the condition is unconstrained.

3.3. Cardinally Explorative Search Procedure for Optimal Location Determination

In the new facility at any suboptimal or optimal situation, say at any arbitrary location, P can physically be any point within the spatial boundary of existing facilities, E_i located at different coordinate points in the cardinal plane and d* is the effective distance. For optimality searching, any coordinate point representing the new facility can be chosen as starting point from where the searching can begin. Assuming that the starting point is (x_0, y_0) for the new facility in the chosen plane having a corresponding value of cost burden (C) as C_0 .

$$\text{Where, } C = \square_{e_i=1}^{n} w_i\, d^*(P, E_I) \qquad (8)$$

The next step is to check the value of C, 1-unit apart in all four cardinal directions (2 on the abscissa and 2 on the ordinate) namely at (x_0, y_0+1); (x_0+1, y_0); $(x_0, y_{0-}1)$; $(x_{0-}1, y_0)$. Supposing that in the 1^{st} iteration, the minimum value at any of the above cardinal points is C_1. Then in the next iteration, the coordinate corresponding to the above minimum C (i.e, C_1) will be treated as the fresh starting point for the next iteration, and so on till the value of C converges to a minimum and the coordinate point (x_m, y_m), corresponding to such minimum value is the optimal location point of the new facility. This algorithmic technique, developed in the optimality modeling software with graphical representation, is oriented with a cardinal exploration based searching through converging series of locational values.

4. Salient Features of the Developed Analytical Software for Locational Optimality.

The construction of the software for analytical solutions of the location analysis problem has been constructed for graphical representation of the optimality framework that can run on a PC and is structured on integrated functional modules. Data Entry for various input of the basis are necessary for defining the problem conditions associated with a new facility location analysis, and pertaining to the coordinate location of facilities, obstacle locations, inter-facility load-flow weightages, and search iteration starting point.Based on the data entry sequence, these existing facilities are automatically numbered as E1, E2, E3, etc., while the quadruple obstacle vertices are numbered like F011, F012, F013, and F014, where the alphabet (F) denotes the forbidden barrier as the succeeding two digits represent the obstacle reference number while the third digit indicates each vertex number of that specific quadrilateral that needs to be keyed in a sequential order for defining the barrier configuration. The iteration starting reference coordinate point is also to be keyed in as the operating input data.

5. Experimental Results

An experimental sample problem-set involving six existing facilities under constrained condition with five forbidden barriers is presented in this section. The results of optimality search using the software are also presented along with the graphical representation of the connecting paths. The problem is formatted in a 50*50 grid space.

Table 3 : Experimental Problem-Set: Parameters Under Constrained Facility Location Situations.

Existing Facility Serial Number	Coordinate Locations of Existing Facilities	Interacting Weight with respect to New Facility
1	(47, 4)	0.15
2	(50,33)	0.15
3	(45,47)	0.20
4	(6, 45)	0.20
5	(0, 1)	0.20
6	(30, 2)	0.10
Barrier Number	**Co-ordinate of Vertices of Quadrilateral Barrier**	
1	(10,39) ; (20,40) ; (20,42) ; (10,43)	
2	(10,5) ; (15,5) ; (15,11) ; (12,11)	
3	(42,5) ; (46,5) ; (45,11) ; (43,11)	
4	(28,7) ; (31,4) ; (34,7) ; (31,10)	
5	(40,42) ; (42,37) ; (46,42) ; (43,44)	

Computerised Output of Analytical Software (with reference coordinate point for initiating optimality search iteration at 25, 25 chosen arbitrarily)Value : 29.43
Point-1 : 25 26 Value : 29.46
Point-2 : 26 25 Value : 29.34 (Next Reference Point with Minimum Value)
Point-3 : 25 24 Value : 29.42
Point-4 : 24 25 Value : 29.54

Graphical representation of the constrained inter-facility connecting path at optimality condition for the problem set is depicted in Figure2 .

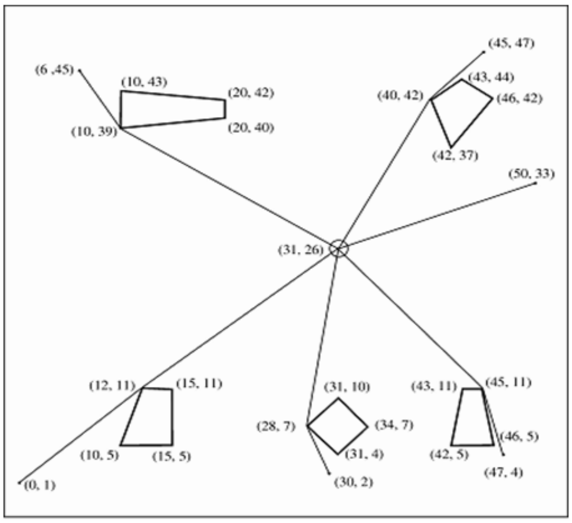

Figure 2: Graphical Representation of the constrained inter-facility connecting path at optimality condition.

Summary of Results:

	Coordinate	Value
1	26 25	29.34
2	27 25	29.27
3	28 25	29.20
4	29 25	29.15
5	30 25	29.12
6	30 26	29.11
7	31 26	29.10
8	31 25	29.11
Optimal: 7th	31 26	29.10

6. Conclusion

The validity testing of the new computational software is established through comparing the results in section 5 with the one using manual computation. With manual computation, it provides the very same value as has been obtained through the DANSORK software for the constrained problem condition as illustrated in the referred section. It has also been shown that the approximation with equivalent configuration does not affect the optimality result in any significant way. These establish the deploy ability of this software and the new obstacle search algorithm for both unconstrained as well as constrained conditions in facility location.

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Total Quality Management in the Top Rank of the Dairy Industry in Jordan

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Abstract

In this paper an investigation was carried out to assess the extent of the individual as well as the collective application of Total Quality Management (TQM) factors in each of the companies of the top rank of the dairy industry in Jordan. The investigation was conducted on the basis of a five point Likert scale survey. Cronbach's Alpha was computed to establish the consistency and reliability of the survey data. Using the score of the collective application of TQM factors in each company as the independent variable, the quantity in tons, of the milk processed for making all the products sold during the year of the survey for each company, was considered as the dependent variable affected by the impacts. Although the extent of the application of TQM factors showed some variation, from factor to factor and from company to another, the investigation established the significance of the extent of the application. It also showed that the correlation between the extent of the overall application and the values of the chosen performance indicator was direct and positive. A discussion of the results of the investigation, in the light of the environment pertinent to the companies**,** was made.

Keywords: TQM application/performance correlation; TQM assessment in the dairy industry; TQM survey

1. Introduction

The variety of dairy products in Jordan typically includes milk, yoghurt (sour milk), labneh (condensed yoghurt), and cheese. Generally speaking, dairy products go through processes that are closely related [1]. Raw milk is primarily stored at a cool temperature. If milk is intended for direct use (drinking, or other purposes), fat content is adjusted, and the milk is homogenized and pasteurised, or sterilized before filling into bottles or other types of containers. In order to make yoghurt, starter cultures are added to ferment the lactose contained in the already homogenized and pasteurised milk. The product is then cooled down, filled into containers and properly stored. After making yoghurt, Labeneh is made through the reduction of the water content down to one third. Cheese making is basically a fermentation and coagulation processes that start after homogenisation and pasteurisation of milk. For fermentation, the right amount of rennet (a natural enzyme) or some industrial substitute is added. The fermentation and coagulation processes lead to the making of curd, which is cut and treated to make the required type of cheese, before washing and storage.

"Total Quality Management (TQM)" was defined as both a philosophy and a set of guiding principles representing the foundation of a continuously improving organization that integrates the fundamental basic management techniques, improvement methods, and technical tools in a wholly disciplined approach [2]. Even before the advent of the 21st century, TQM had developed in many countries into holistic frameworks aiming at helping organizations achieve world class excellence [3]. Research in TQM, at the beginning, was mainly confined to conceptual case studies [4]. Over the past few years, survey-based TQM research followed, especially in the area of identification and assessment of TQM factors. According to Sila and Ebrahimpur [5], 347 survey-based studies were published between 1989 and 2000. These studies dealt with, amongst other things, the very significant topics of critical factor identification, and measurement as well as the assessment of the impacts of the so called TQM factors [6].

In Jordan, there have been several studies that focused on the assessment of the extent of application and the impacts of TQM in areas other than the dairy industry [7-9]. The assessment of the extent of application and the impacts of TQM in the Jordan dairy industry, to the best of researchers' knowledge, has not been addressed so far. The dairy industry in Jordan comprises private sector companies. These companies widely vary in technology, age, size, location, and scope of the product mix. To make any investigation result in meaningful conclusions, segmentation of the industry was seen imperative. Accordingly, it was decided to select the most developed and best established companies of the sector. On the basis of a survey involving the dairy companies and the major departmental stores and supermarkets, it was concluded that this section comprised six companies. These companies used modern technology, and they were well settled in terms of share in the market and capacity utilization, and practically offered the same types of products. One of the companies was not prepared to be

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involved, leaving five companies that underwent the investigation.

The aim of this investigation is to judge the progress of the overall TQM application and to assess the impacts on the performance in each of these five companies. This will cover two aspects namely:

- The extent of the application of the individual TQM factors and the application of all these factors collectively in each individual company.
- The impacts of the TQM factors, collectively applied, on the performance indicator of each individual company.

Towards this end, it was decided to resort to a survey based on a suitably designed and carefully distributed questionnaire that included statements pertinent to each type of TQM factors. For each company, responses to the statements are assessed on a five point Likert scale. On the basis of the statements scores, the factor scores and the individual company overall TQM application score are assessed. Testing of the hypothesis will assess the significance of the application of each factor and all the factors in each company. To judge the impact of TQM on the companies, the overall TQM application score of each company was envisaged as an independent variable. The quantity in tons, of the milk processed for making all the products sold during the year of the survey for each company, was considered as the dependent variable affected by the impacts.

As the managements of the companies considered their business quality indicators sensitive information, it was agreed that companies will be referred to by their designations (C_c), ranging from C_1 to C_5.

2. Identification of TQM Factors and The Design of The Questionnaire

The identification of the factors contributing to TQM varied extensively. Sila and Ebrahimpur [5], on the basis of a survey research, extracted 25 most commonly quoted factors. Applying a cause-and-effect analysis, these factors boiled down to what Besterfield [2] identified as the five main bases of TQM, namely: instilling quality culture, the so called quality chain (treating each element as a customer and producer simultaneously), quality assurance, commitment to continuous improvement and finally the support of top management. The establishment of these bases required attention to several areas of resource management. The required actions were described as TQM enablers or factors. Through some cause-and-effect analysis, the basic enablers, meaning TQM factors, were reduced to the following:

- Instilling quality culture
- Focus on employees involving employee participation, training and motivation
- Focus on operations including continuous improvement
- Focus on customers
- Strategic competitive management

The essence of each of the factors above is reflected by the statements of the questionnaire (shown in the Appendix as Figure I) dedicated to measure that factor.

The above five factors were considered variables through which the extent of the application of TQM in each company is measured. For each company, the assessment of these variables is made on the basis of the statements of the questionnaire designed for the purpose of the investigation.

The questionnaire, as shown in Figure I, consists of five sections. Each section is dedicated to measure one of the TQM factors. Each section comprised a number of statements. The responses to each statement are meant to reflect the status quo of some aspect of the factor. Five predesignated responses (R_1 to R_5) are envisaged. The response designation, the essence of the response and the response value on the five point Likert scale, are as follows:

Response designation	R_1	R_2	R_3	R_4	R_5
Type of response	Never	Rarely	Sometimes	Often	Always
Likert scale value	1	2	3	4	5

For each company the responses to each statement are considered as a sample from the population relevant to the pertinent factor of the pertinent company. The number of the valid copies of the questionnaire, finally used for the survey, will make the size of this sample.

3. Proposed Statistical Treatment and Analysis

To examine the consistency and reliability of the data collected on the basis of the questionnaire, the Cronbach's Alpha of the data is proposed to be computed using the following formula [10]:

$$CAlpha = \left[\frac{K}{K-1}\right] * \left[1 - \frac{\sum Var_c}{TVar_c}\right]$$

Where: CAlpha = Cronbach's Alpha

K = the number of statements in the test (questionnaire)

$\sum Var_c$ = the sum of the variances of the scores of the statements of the individual companies .

$TVar_c$ = the variance of the totals of the scores of the statements of the individual companies For most applications a Cronbach's Alpha of 0.8 or higher is considered acceptable

For the statistical treatment of the variables relevant to each company (C_c), the responses (X_{ji}) to each statement (S_i) of each factor (F_j) are assessed, and the mean value of the responses ($\overline{X}_{ji}$) as well as the standard deviation ($\sigma_{x,ji}$) are computed. The central tendency of the extent of application of each factor is measured by the mean of the means of the factor statement scores, $F\overline{X}_j = \overline{\overline{X}}_{ji}$. The dispersion of the extent of application of each factor is measured by the mean of the standard deviations of the factor statements scores, $F\sigma_{x,j} = \overline{\sigma}_{x,ji}$.

As the number of statements relevant to each factor varies, the central tendency for the extent of the overall application of TQM (represented by all the factors in each company) is measured by the weighted mean of the means of the factors

$C\overline{X}_c = \sum_j (w_j * F\overline{X}_j) / \sum_j w_j$,where (w_j) is the number of statements involved in each factor.

Similarly the dispersion of the extent of the overall application of TQM (represented by all the factors in each company) is measured by the weighted average of the standard deviations of the factors

$$C\sigma_{x,c} = \sum_j (w_j * F\sigma_{x,j}) / \sum_j w_j \ .$$

The number of responses (n) to each statement is deliberately made large enough to justify using the standard deviation of the sample for the standard deviation of the population. Also, using a large enough sample size justifies the assumption of a normal distribution of the mean of the sample [11]. As such, the standard deviation of the factor statements' means is $F\sigma_{\bar{x},j} = F\sigma_{x,j}/\sqrt{n}$ and that of the company overall TQM application statements' means is $C\sigma_{\bar{x},c} = C\sigma_{x,c}/\sqrt{n}$.

Hypothesis testing is envisaged to judge if the extent of the application of each TQM factor as well as the overall TQM application (represented by all the factors together) in each company is significantly above the Likert scale nominal average of μ=3 or not. This is planned to be achieved as follows:

3.1. Formulation of Hypothesis

- On the factor level
  Null hypothesis H_0: the company does not apply the factor: μ<=3, Alternative hypothesis H_1: the company applies the factor: μ>3
- On the TQM Level
  Null hypothesis H_0: the company does not apply TQM: μ<=3, Alternative hypothesis H_1: the company applies TQM: μ>3

3.2. Level of Significance (a)

A one sided level of significance, where α = 0.05, is envisaged; this level of significance, for a normal distribution, is associated with Z- values as follows:

- On The Factor Level, The Z-Value:

$$FZ_j <= 1.645$$

- On The Company TQM Application Level, The Z-Value:

$$CZ_c <= 1.645$$

3.3. Judgement Criteria

- On the factor level:
  Reject H_0 when FZj =

$$(F\bar{X}_j - 3) / F\sigma_{\bar{x},j} > 1.645$$

- On The Company TQM Application Level:
  Reject H_0 when

$$Z_c = C(C\bar{X}_j - 3) / C\sigma_{\bar{x},c} > 1.645$$

Considering the settled statuses of the companies, the quantity in tons of the milk processed for making all the products sold by each company during the year of the survey was considered as the dependent variable affected by the impacts. To determine the impacts of TQM application on each company, the dependant variable relevant to that company is plotted against the independent variable (the value of TQM application score in that company, $C\bar{X}_c$). Regression analysis is used to determine the correlation coefficient between the variables.

4. Field work and Assessments

The questionnaire subject matter of Figure I was organized in two sections: A & B. Section A was meant to be answered solely by random samples of the employees of each company. Section B was meant to be randomly answered, in equal proportions, by the employees as well as by the customers of each company. The total distribution of the questionnaire, the number returned, and the number considered valid for analysis are as shown below.

Copies distributed	Number returned	Valid number used for the analysis
250	188	150

Aiming for what could be considered as a large sample size [11], it was decided to settle for randomly selecting 30 properly completed copies for each company.

Relevant to each company, the responses to the statements of the questionnaire were analysed, and the means $\bar{X}_{ji}$ and the standard deviations $\sigma_{x,ji}$ for each statement were computed. Also, for each company (C_c), for each factor (F_j), the values of $F\bar{X}_j$, $F\sigma_{x,j}$, $C\bar{X}_c$ and $C\sigma_{x,c}$ were also computed. The organization of the data and the results of the computations relevant to the individual companies are shown in the Appendix as Figure II. Accordingly, the mean score of the application amongst the five companies is 3.4104, and the standard deviation of the scores is 0.3241 - thus providing a coefficient of variation of 9.5%.

On the basis of the data organised in Figure II, the consistency and reliability of the responses to the statements of the questionnaire were examined as a whole, using the Cronbach's alpha formula. The body of the data comprised five columns, each representing the means of the scores of the responses to the statements of the questionnaire relevant to one company. The computed value of the Cronbach's alpha coefficient of the data was 1.005, which is significantly higher than the minimum acceptable value of 0.8.

For each company (C_c) for each factor (F_j), the values of $F\bar{X}_j$, $F\sigma_{x,j}$, $C\bar{X}_c$ and $C\sigma_{x,c}$ were extracted from Figure II and used to assess the values of $F\sigma_{\bar{x},j}$, FZ_j , $C\sigma_{\bar{x},c}$ and CZ_c . These computations, the decisions regarding hypothesis testing, and conclusions based on the decisions are shown in the appendix as Figure III.

For the impact of the extent of the overall applications of TQM in each of the companies, the value of the dependant variable (tons of milk processed) relevant to that company was obtained from the company management. These values, as well the values of the independent variable (the scores of the overall TQM application in each company) as obtained from figure II, are shown in Figure 1.

A curve representing the value of the dependant variable (tons of milk processed) in each company against the independent variable (the score corresponding to the extent of the overall application of TQM in that company) is shown in Figure 2.

As indicated by the shape of the curve, linear regression could be assumed. To assess the proportion of the variation in the dependant variable that could be attributed to the linear relationship with the independent variable, the coefficient of correlation (r) was assessed as follows (Miller, Freund and Johnson 2004):

$$r = \frac{n\sum XY - \sum X \sum Y}{\sqrt{\left[n\sum X^2 - \left(\sum X\right)^2\right]\left[n\sum Y^2 - \left(\sum Y\right)^2\right]}}$$

where X= the independent variable
Y= the dependant variable
n= the number of observations

The value of the coefficient of correlation of the dependant variable was 0.94

Company	C_1	C_2	C_3	C_4	C_5
Independent Variable					
- Mean TQM score	3.387	3.505	3.945	2.955	3.260
Dependant Variables					
Tons of milk processed per year	17500	15500	21500	7800	10900

Figure 1: Values of the independent and dependant variables for the Companies.

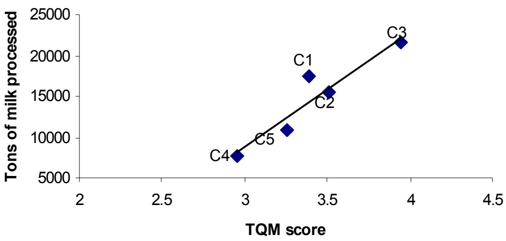

Figure 2: Impacts of TQM on performance.

5. Discussion of Results

The Cronbach's alpha value for the companies' scores of 1.005 is well above the minimum acceptable value of 0.8, thus indicating that the design and the distribution of the questionnaire, taken as a whole, managed to provide the necessary consistency and reliability of the data.

TQM factor application, as obtained from Figure II, showed that the companies varied over the attention they paid to the various factors. The "focus on operations" averaging 3.958 and "focus on instilling TQM culture" averaging 3.709 received the highest attention. The "focus on employees" averaging 2.876 received the lowest. As far as the "attention to employees" is concerned all the companies except C3 scored below the nominal average of 3.0. Generally speaking, factor attention goes in line with the prevailing attitude of seeking excellence through spending on equipment and preaching for good performance without paying sufficient attention to the necessary development of human resources. In fact, a previous investigation involving the health sector gave similar results [9]. Although the companies did significantly focus on the "attention to customers", this factor ranked second from the bottom. Marketwise, this situation resulted in the fact that imports of dairy products of comparable quality and prices still capture a share of the market.

6. Conclusions and Recommendations

The mean overall TQM application scores on the 5 point Likert scale for the relevant companies as obtained from Figure II and the percentages these scores represent out of the maximum possible score are shown below.

Company	C_1	C_2	C_3	C_4	C_5
Mean TQM application score	3.387	3.505	3.945	2.955	3.260
% representation of the max. possible score	0.677	0.701	0.789	0.591	0.652

Considering hypothesis testing, Figure III indicated that companies C1, C2 and C3 significantly applied TQM while C4 and C5 did not. Company C3, the youngest of the companies and the most modern achieved the highest score of 3.945, and company C4, the oldest and least modern, scored the minimum of 2.9545.

The relationships between the values of the performance indicator (Tons of milk processed per year) and the overall TQM scores of the companies are shown by the curve of Figure 2. The correlation coefficient was 0.94, indicating a direct and consistent linear relationship.

This survey-based investigation managed to contribute to the application of TQM in dairy industry in Jordan through the assessment of the extent of the factor as well as the overall TQM application in each of the companies subject matter of the investigation. It also managed to assess the impact of the application on the performance indicator. As this investigation sheds the light on the status quo, it points to the direction and the extent of some relevant actions required in the relevant areas.

Similar investigations are recommended for other industries in Jordan, where the scopes for improvements are widely needed.

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Appendix

Statement no: S_i	Quality statement
	1- Instilling quality culture
S_1	Plans for TQM are prepared and discussed on a large scale.
S_2	Employees are educated to observe public hygiene requirements.
S_3	Employees are educated to observe infection prevention procedures
S_4	Employees are regularly scanned for safety from infectious diseases
S_5	TQM plans, procedures ,instructions, reports and documents are documented for easy access and reference
S_6	Top management helps in instilling beliefs, integrity and devotion through out the organization.
S_7	Sterility of equipment and material is asserted
S_8	Performance measures are explained to all employees by top management.
S_9	Top management explains the concept of quality chain (customer/supplier interface) to all employees.
S10	The bases of TQM and its benefits are properly explained for all employees in the organization
S11	Management clarifies the importance of the human role in achieving quality and customer satisfaction.
S12	Management explains to employees what they are trying to achieve and how they can meet the objectives.
S13	Management tries to change attitudes from simply working to finish a job to working to achieve an outcome.
	2- Focus on employees
S_{14}	Employees are involved in decision making concerning their specialty.
S_{15}	Management allows employees to participate and make suggestions in solving problems in their own departments.
S_{16}	Management effectively encourages team work
S_{17}	Human resource department has effective role in helping employees overcome problems at work.
S_{18}	Adequate authority is given to employees according to their specialization
S_{19}	Collective incentives recognizing individual contributions are granted
S_{20}	Team incentives are granted according to the level of contribution in favor of the company
S_{21}	Management encourages constructive competition between employees and departments.
S_{22}	Employees are held accountable for not doing their job properly.
S_{23}	Employees are rewarded morally for excelling in their jobs.
S_{24}	The organization has a training department or training section.
S_{25}	Annual Budgets for training are adequate.
S_{26}	Trainers and advisors are available to help new recruits
S_{27}	Sometimes trainees are employed to conduct further training downstream
S28	Training-equipment and facilities are available and efficient.
S29	Training plans, procedures, instructions, reports and documents are documented for easy access and reference
S30	Employees are trained for multiple jobs and tasks.
S31	Employees are evaluated to ensure proper training
S32	Employees are trained in quality improvement skills.
S33	Employees are supported when seeking higher qualifications
S34	Employees are trained in problem identification and problem solving techniques.

S35	Social security and health insurance schemes are available
S36	Top management encourages participation in social events.
S37	Management organizes social and recreational activities
S38	Management applies a profit sharing scheme
3- Focus on operations including continuous improvements	
S39	Management attracts the best of the resources
S_{40}	The company strives to improve the quality of dairy products and enhance their storage life.
S_{41}	The company has a research and development department or team.
S_{42}	The company uses new technologies to reduce waste and improve quality and productivity.
S_{43}	The company has strict cleaning procedures for workers and machines to ensure food safety.
S_{44}	Management follows a policy of benchmarking targets.
S_{45}	Various tests are conducted in different stages of the production process to ensure good quality
S_{46}	Suppliers are evaluated concerning the quality, delivery time, reliability and cost of their supplies (raw milk).
S47	Material handling techniques are improved to minimize waste of time.
S48	Management treats each section as a client and producer simultaneously.
S49	Environmental conditions such as temperature and humidity are accurately controlled to avoid variations in product quality and to ensure product safety.
S50	Management keeps written records of testing, to detect variations in the production process that affect product quality and safety.
S51	Operational and supporting staff are kept updated for relevant developments
S52	New products are introduced to increase sales and market shares.
S53	Management uses all means available to minimize cost and improve quality.
S54	All means are employed to minimize errors and mistakes.
S55	Testing equipments are regularly serviced, maintained and calibrated.
S56	.Equipments and appliances are regularly serviced, maintained and/or calibrated
S57	Management regularly updates testing equipments.
4- Focus on customers	
S58	Market research is carried out on regular basis to assess customers' needs, expectations and satisfaction.
S59	Customers' complaints are taken seriously, and actually considered.
S60	Products are packaged in different forms and sizes
S61	Management uses the media to keep the public well informed about the improved/New products.
S62	Supply and delivery of products are reliable
S63	Direct and indirect contacts between customers and employees are systematically encouraged and organized
S64	Customer support systems such as website and/or a 24 hours phone service are used to ensure contacts with customers.
5- Assessment of quality performance	
S65	Plans for future improvements are prepared
S66	Developments in the dairy industry, else where, are monitored and introduced.
S67	Strategic plans are customer driven.
S68	Quality audits are conducted in the various sections of the company.
S69	Top management sets specific and clear vision, mission, and strategies and makes them understood by all employees of the company.
S70	Management keeps open channels where employees can send and receive information.
S71	Management keeps easy and effective communication with and among all the company employees, suppliers and customers.

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S72	Quality is measured in each and every department all over the organization.
S73	Statistical quality control is used in the company.
S74	The company uses statistical ways to aid in measuring and controlling the quality of the products and processes.
S75	Quality assessment results are used to improve factory's performance.
S76	Quality measures set by the company contribute to improve overall performance.
S77	The company management system is regularly revised and updated.
S78	The company checks the validity and reliability of the quality assurance measures.
S79	An effective production planning system is used

Figure I: The questionnaire.

Quality statement no.: S_i	**Companies (Cc)**									
	C_1		C_2		C_3		C_4		C_5	
	$\overline{X}_{ji}$	$\sigma_{x,ji}$	$\overline{X}_{ji}$	$\sigma_{x,ji}$	$\overline{X}_{ji}$	$\sigma_{x,ji}$	$\overline{X}_{ji}$	$\sigma_{x,ji}$	$\overline{X}_{ji}$	$\sigma_{x,ji}$
1- Instilling quality culture										
S_1	3.07	1.230	4.03	0.809	4.00	0.263	3.23	1.382	3.43	1.006
S_2	4.27	0.944	4.63	0.556	3.83	0.834	4.27	0.980	4.47	0.776
S_3	3.63	1.299	3.90	1.125	4.20	0.484	3.33	1.373	3.87	1.383
S_4	4.67	0.884	4.83	0.531	3.83	0.986	4.43	1.008	4.83	0.531
S_5	4.70	0.596	4.67	0.802	3.77	0.679	3.37	1.497	4.07	1.048
S_6	3.17	1.341	4.17	1.053	4.40	0.563	3.63	1.217	3.53	1.224
S_7	4.73	0.521	4.87	0.434	4.73	0.450	4.47	0.860	4.53	0.730
S_8	3.30	1.291	4.03	0.964	3.83	0.461	3.07	1.172	3.07	1.202
S_9	2.60	1.192	3.67	1.155	4.17	0.461	2.53	1.502	3.00	1.259
S10	3.10	1.348	3.70	0.952	3.63	0.490	2.13	1.279	2.20	1.215
S11	3.33	1.269	3.73	1.112	4.23	0.430	2.83	1.392	3.07	1.507
S12	3.10	1.348	3.67	1.155	4.10	0.305	2.70	1.208	3.00	1.462
S13	2.90	1.373	3.27	1.337	4.23	0.430	2.53	1.252	2.83	1.392
TQM factor statistics in each company										
$F\overline{X}_j = F\overline{X}_1$	3.582		4.090		4.073		3.271		3.531	
$F\sigma_{x,j} = F\sigma_{x,1}$		1.126		0.922		0.526		1.240		1.133
2- Focus on employees										
S_{14}	2.57	1.104	3.00	1.259	4.23	0.568	3.00	1.554	3.03	1.245
S_{15}	2.53	0.973	3.03	1.299	3.33	0.479	3.03	1.629	3.13	1.408
S_{16}	2.70	1.149	3.40	1.248	4.07	0.365	2.83	1.367	3.57	1.223
S_{17}	2.47	1.224	2.77	1.547	3.90	0.712	1.97	1.299	3.20	1.540
S_{18}	2.77	1.073	3.10	1.494	4.20	0.847	2.97	1.608	3.23	1.251
S_{19}	2.37	1.326	2.57	1.524	3.83	0.986	2.90	1.447	3.00	1.145
S_{20}	1.83	1.147	2.90	1.626	3.83	0.747	2.33	1.213	3.00	1.390
S21	1.80	1.064	2.47	1.332	4.13	0.730	2.53	1.224	2.63	1.351
S_{22}	4.03	0.999	4.63	0.669	4.17	1.206	4.33	0.959	4.17	1.234
S_{23}	2.27	0.785	2.50	1.383	3.67	0.884	2.4	1.221	2.87	1.332
S_{24}	2.90	1.269	1.57	1.223	2.97	0.556	1.27	0.785	1.67	1.124
S_{25}	2.40	1.133	1.63	1.245	3.17	0.791	1.33	0.758	1.63	1.066
S_{26}	3.03	1.217	1.57	1.223	3.60	0.563	3.03	1.691	2.80	1.472
S_{27}	2.93	1.143	1.73	1.337	3.77	1.223	1.7	0.837	2.37	1.402
S_{28}	2.80	1.126	1.60	0.968	3.77	0.504	2.20	1.270	2.63	1.402

S_{29}	3.00	1.232	1.83	1.020	4.40	0.563	1.8	1.126	2.43	1.431
S30	3.70	1.179	3.53	1.137	3.93	0.450	3.90	1.322	3.60	1.102
S31	2.77	1.165	2.13	1.548	4.50	0.682	2.13	1.252	2.57	1.305
S32	3.70	1.088	3.40	1.303	4.73	0.450	2.8	1.472	3.17	1.177
S33	2.20	1.031	1.60	1.276	3.57	0.504	2.03	1.189	2.00	1.203
S34	2.97	1.129	2.40	1.476	3.67	0.802	2.50	1.225	2.37	1.299
S35	4.87	0.434	5.00	0.000	4.27	0.828	4.37	1.217	4.73	0.521
S36	1.80	0.961	1.73	1.258	2.60	1.329	2.83	1.599	1.73	1.048
S37	1.63	0.999	1.83	1.289	3.03	0.964	2.97	1.542	2.00	1.114
S38	1.33	0.884	1.67	1.398	3.33	0.884	1.20	0.761	1.97	1.326
TQM factor statistics in each company										
$F\overline{X}_j = F\overline{X}_2$	2.695		2.544		3.787		2.574		2.780	
$F\sigma_{x,j} = F\sigma_{x,2}$		1.073		1.243		0.745		1.263		1.244
3- Focus on operations including continuous improvements										
S39	4.20	0.961	4.57	0.568	4.67	0.547	3.23	1.331	4.00	0.947
S_{40}	4.43	1.073	4.67	0.711	4.33	0.479	3.70	1.119	4.00	0.947
S_{41}	2.20	1.540	3.17	1.683	3.10	1.155	2.27	1.507	2.30	1.535
S_{42}	3.93	0.980	4.43	0.858	4.40	0.498	3.27	1.311	3.57	1.135
S_{43}	4.43	1.073	4.67	0.479	4.67	0.711	3.93	1.143	4.07	0.785
S_{44}	3.83	1.085	4.33	0.606	3.73	0.583	3.10	1.348	3.63	1.159
S_{45}	4.77	0.430	5.00	0.000	4.70	0.466	3.93	1.258	4.30	0.915
S_{46}	4.60	0.675	4.87	0.346	4.30	0.794	4.20	1.157	4.47	0.860
S47	3.87	0.937	4.07	1.015	4.47	0.571	3.77	1.331	3.90	1.062
S48	2.97	1.245	2.83	1.555	3.43	0.858	2.30	1.393	2.97	1.189
S49	4.13	1.008	4.43	0.898	4.90	0.305	3.67	1.322	4.47	0.629
S50	4.47	0.776	4.90	0.305	4.53	0.571	4.63	1.033	4.60	0.932
S51	3.07	1.230	3.30	1.055	3.90	0.759	3.5	1.306	3.33	1.322
S52	4.13	1.106	4.23	0.774	3.50	0.938	3.23	1.305	3.77	1.194
S53	4.03	0.999	4.30	0.702	4.60	0.563	4.00	1.174	4.17	1.085
S54	3.63	1.273	4.37	0.850	3.93	0.785	3.67	1.398	3.87	0.900
S55	4.27	1.285	4.50	0.682	4.50	0.572	3.40	1.276	4.17	0.834
S56	4.43	0.898	4.53	0.507	4.20	0.484	3.5	1.358	4.00	1.017
S57	4.10	0.923	4.47	0.730	3.33	0.802	3.03	1.351	3.73	1.230
TQM factor statistics in each company										
$F\overline{X}_j = F\overline{X}_3$	3.973		4.297		4.168		3.491		3.859	
$F\sigma_{x,j} = F\sigma_{x,3}$		1.026		0.754		0.655		1.285		1.036
4- Focus on customers										
S58	3.77	1.165	3.50	1.225	3.77	0.858	2.60	1.102	2.43	1.073
S59	4.47	0.860	4.13	1.074	4.70	0.466	3.77	1.135	4.13	0.900
S60	3.33	1.269	2.87	1.358	2.67	1.028	3.53	1.279	2.73	1.363
S61	3.80	1.095	3.50	1.075	3.53	1.042	2.67	1.184	2.00	0.910
S62	2.77	1.305	3.30	1.149	2.97	1.245	2.50	1.280	2.10	1.029
S63	3.17	1.440	2.20	1.375	3.33	1.241	2.70	1.179	2.07	1.230
S64	3.63	1.377	3.63	0.999	3.13	1.479	2.60	1.522	2.43	1.305
TQM factor statistics in each company										
$F\overline{X}_j = F\overline{X}_4$	3.563		3.304		3.443		2.910		2.556	
$F\sigma_{x,j} = F\sigma_{x,4}$		1.216		1.179		1.051		1.240		1.116

5- Strategic competitive management										
S65	4.10	0.803	4.23	0.728	4.67	0.479	2.50	1.306	3.77	1.104
S66	3.43	1.194	3.03	1.189	4.37	0.850	2.47	1.279	2.83	1.206
S67	3.70	0.988	3.57	0.898	3.93	0.254	2.53	1.306	3.30	0.837
S68	3.80	1.064	4.27	1.015	4.27	0.785	3.43	1.431	3.77	0.935
S69	3.10	1.296	3.63	1.299	3.43	0.568	2.37	1.326	2.83	0.950
S70	3.00	1.145	3.10	1.296	3.90	0.885	3.57	1.591	3.63	1.217
S71	2.97	1.273	3.23	1.223	4.23	0.568	2.77	1.591	3.27	1.112
S72	3.77	0.858	4.10	0.759	4.30	0.535	3.27	1.363	3.33	1.241
S73	3.50	0.900	3.90	1.125	3.50	0.682	2.7	1.368	3.40	0.932
S74	3.77	0.898	3.80	1.243	3.53	0.681	2.33	1.422	3.30	1.291
S75	3.40	0.724	3.97	0.999	3.93	0.583	2.27	1.258	3.60	1.163
S76	3.73	0.785	3.87	1.042	4.30	0.466	2.83	1.341	3.70	1.291
S77	3.83	1.177	3.13	1.525	4.23	1.194	2.27	1.311	3.03	1.189
S78	3.67	0.844	3.50	1.225	4.00	0.695	2.20	1.215	3.40	1.329
S79	3.43	1.194	4.03	0.964	4.17	0.834	2.37	1.426	3.80	1.186
TQM factor statistics in each company										
$F\overline{X}_j = F\overline{X}_5$	3.547		3.691		4.051		2.659		3.397	
$F\sigma_{x,j} = F\sigma_{x,5}$		1.009		1.102		0.671		1.369		1.132
Overall TQM application statistics in each company										
$C\overline{X}c$	3.387		3.505		3.945		2.955		3.260	
$C\sigma_{x,c}$		1.071		1.040		0.700		1.283		1.143

Figure II: Responses to the questionnaire and computation of the factor and overall application scores.

Company C_c	Factor F_j	$F\overline{X}_j$	$F\sigma_{x,j}$	$F\sigma_{\bar{x},j}$	FZ_j	Decision	Conclusion
C_1	j=1	3.582	1.126	0.205579	2.831035	Reject H_0	Factor applied
	j=2	2.695	1.073	0.195902	-1.5569	Accept H_0	Factor not applied
	j=3	3.973	1.026	0.187321	5.194289	Reject H_0	Factor applied
	j=4	3.563	1.216	0.22201	2.535919	Reject H_0	Factor applied
	j=5	3.547	1.009	0.184217	2.969319	Reject H_0	Factor applied
	TQM application in company C_1						
		$C\overline{X}_1$	$C\sigma_{x,1}$	$C\sigma_{\bar{x},1}$	CZ_1	Decision	Conclusion
		3.387	1.071	0.196	1.974	Reject H_0	Company applies TQM
C_2	j=1	4.090	0.922	0.168	6.475	Reject H_0	Factor applied
	j=2	2.544	1.243	0.227	-2.009	Accept H_0	Factor not applied
	j=3	4.297	0.745	0.136	9.536	Reject H_0	Factor applied
	j=4	3.304	1.179	0.215	1.412	Accept H_0	Factor not applied
	j=5	3.691	1.102	0.201	3.434	Reject H_0	Factor applied
	TQM application in company C_2						
		$C\overline{X}_2$	$C\sigma_{x,2}$	$C\sigma_{\bar{x},2}$	CZ_2	Decision	Conclusion
		3.505	1.040	0.190	2.658	Reject H_0	Company applies TQM
C_3	j=1	4.073	0.526	0.096	11.173	Reject H_0	Factor applied
	j=2	3.787	0.745	0.136	5.786	Reject H_0	Factor applied
	j=3	4.168	0.655	0.120	9.767	Reject H_0	Factor applied
	j=4	3.443	1.051	0.192	2.309	Reject H_0	Factor applied
	j=5	4.051	0.671	0.123	8.579	Reject H_0	Factor applied

	TQM application in company C_3						
		$C\overline{X}_3$	$C\sigma_{x,3}$	$C\sigma_{\bar{x},3}$	CZ_3	Decision	Conclusion
		3.945	0.700	0.128	7.383	Reject H_0	Company applies TQM
C_4	j=1	3.271	1.240	0.226	1.197	Reject H_0	Factor applied
	j=2	2.574	1.263	0.231	-1.847	Accept H_0	Factor not applied
	j=3	3.491	1.285	0.235	2.093	Reject H_0	Factor applied
	j=4	2.910	1.240	0.226	-0.398	Accept H_0	Factor not applied
	j=5	2.659	1.369	0.250	-1.364	Accept H_0	Factor not applied
	TQM application in company C_4						
		$C\overline{X}_4$	$C\sigma_{x,4}$	$C\sigma_{\bar{x},4}$	CZ_4	Decision	Conclusion
		2.955	1.283	0.234	-0.192	Accept H_0	Company does not apply TQM
C_5	j=1	3.531	1.133	0.207	2.567	Reject H_0	Factor applied
	j=2	2.780	1.244	0.227	-0.969	Accept H_0	Factor not applied
	j=3	3.859	1.036	0.189	4.541	Reject H_0	Factor applied
	j=4	2.556	1.116	0.204	-2.179	Accept H_0	Factor not applied
	j=5	3.397	1.132	0.207	1.921	Reject H_0	Factor applied
	TQM application in company C_5						
		$C\overline{X}_5$	$C\sigma_{x,5}$	$C\sigma_{\bar{x},5}$	CZ_5	Decision	Conclusion
		3.260	1.143	0.209	1.281	Accept H_0	Company does not apply TQM

Figure III: Hypothesis testing .

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Automated Maintenance Approach for Industrial Machineries by Soft Computing Techniques at Offline Monitoring Process

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Abstract

Fault diagnosis of industrial machineries become very much important for improving the quality of the manufacturing as well as for reducing the cost for product testing. In modern manufacturing scenario, a fast and reliable diagnosis system has turned into a challenging issue in the complex industrial environment. In this work, the diagnosis of gearbox is considered as a mean of health monitoring system by used lubricant. The proposed methodology has been performed on the basis of wear particle analysis in gearbox at offline stage. Possible wear characterization has been done by image vision system to interpret into soft computing techniques like fuzzy inference and neural network mechanisms. Basically, the maintenance policy has been taken with the help of fuzzy expert system, which has been described in the present work.

Keywords: Wear Particle Analysis; Fractal Mathematics; Artificial Neural Network; Fuzzy System; Image Processing System

1. Introduction

The manufacturing industries have already started on the issue of cost of equipment, maintenance, and its simultaneous services with reliability factors since the last few decades. These kinds of effects generally prevail on sectors such as; power generation, refinery, transportation and so on. Even other factors such as; parts, labor, equipment downtime, lubricant prices, disposal costs are also the primary concern in a well-run maintenance program. Machine condition monitoring has found prerequisite maintenance programs amongst all other methodologies [1]. But lubricant analysis has found one of the suitable techniques in machine monitoring processes, popularly known as wear particle analysis. Based on lubricant analysis, the diagnosis of equipments can be done properly as it involves continuous process. Lubricant analysis and its positive effects is revealed in Figure1.

Some of the reasons have been considered for economic analysis in machine monitoring system such as;

- total machine reliability
- reduction of downtime
- increased throughput
- reduced operations risks
- savings on operation and management budget
- detailed knowledge of machinery(s)
- operational excellence

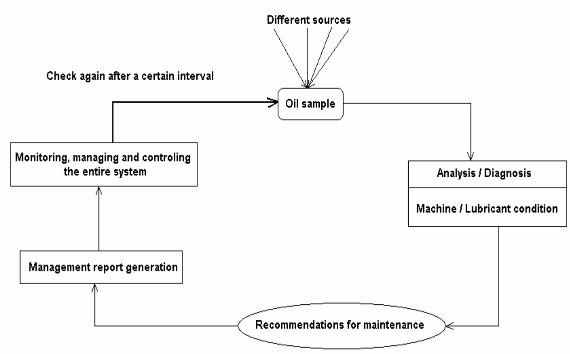

Figure1: Lubricant analysis for monitoring condition.

Maintenance of machineries and recognizing the possible faults in their entire lifecycle have been found as the most important arena in the industrial sector. After successful installation of various automatic machineries in different types of industrial level, governments have already started reviewing the economies so that the unnecessary waste of accessories can be prevented with suitable maintenance policies. Commercial advantages of maintenance have been adopted for the last few decades just to reduce the costs of the entire activities by including the original equipment features to facilitate maintenance tasks. In most industries, condition monitoring is adopted to provide the maximum possible technical solutions in on-going condition assessment, fault prediction, fault detection, location, classification and so on [2]. Some of the most standard monitoring techniques can be handled in the equipments like,

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- Gearboxes [tooth stiffness measurements, mesh modeling, detection-location-diagnosis and severity assessment of different cracks and so on]
- Aerospace structures
- Compressors
- Diesel engines
- Robotics

In the present work, fault diagnosis has been done on the basis of wear particle analysis by using some mathematical interpretations with soft computing techniques.

2. Automated Wear Particle Analysis

Wear is basically the damage to any surface that generally involves sufficient loss of materials and it may occur as a result of relative motion between that surface and the contacting substances. Wear particle investigations and fault diagnosis of different machineries are not a new topic in maintenance engineering rather in the field of tribology. This technique has already been accepted as an effective and economic method to detect the actual condition of machine. Also, preventive maintenance strategy can be performed on machines if it applies properly [3]. Due to some shortcomings in traditional wear analysis, digitized image vision has become one of the solutions for the problems associated with conventional techniques, especially in case of off-line condition monitoring. Wear mechanism has been classified in several ways by many researchers or industry people. Wear mechanism depends mainly on the two surfaces in contact to each other. Basically, there are two types of wear occur in any machine interaction i.e.

- Mechanical wear (associated with friction, abrasion, impact and fatigue)
- Chemical wear (it attacks the surface by reactive compounds and subsequent removal of the products of reaction by mechanical action)

The maintenance strategy based on monitoring of machinery can be elucidated in various ways but the essential element has been indicated in Figure2.

It is a quite well known phenomenon that lubrication is one of the best modes of detection of wear amongst other techniques, but wear particle distributions may be characterized based on the features such as;

- material
- size
- shape
- concentration

The probable damages may occur in gearbox of any industrial machineries, which is shown in Figure3. Wear particles can be simplified as normal particles, fatigue particles, sliding particles, characteristic particlesatrunning in condition, red oxides, black oxides, cutting particles, ball particles, wear polymerides, particles from corrosive wear, impurities, non-ferrous particles, and etc. [4].

3. Wear Measurement Techniques

Ferrography techniques have been found as one of the suitable measurement techniques of wear debris. It may provide the sufficient characteristics of particles, so that

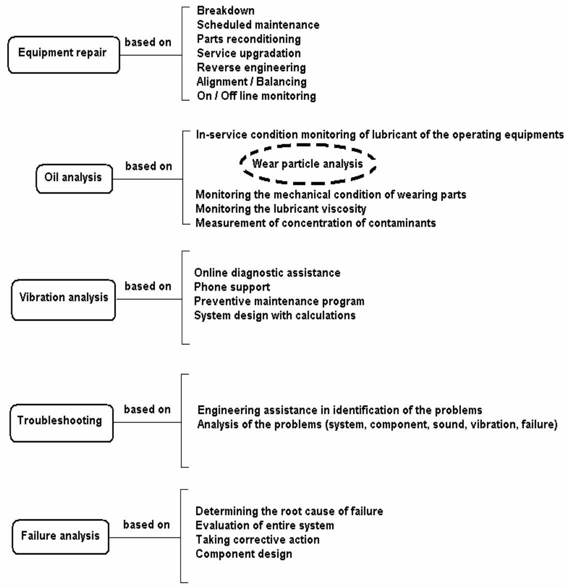

Figure 2: Strategic actions of maintenance based on condition monitoring of machines.

the operating wear modes within machines may be determined. It can allow the prediction of imminent behavior of machines. It can be used routinely to monitor the condition and wear of the critical components at higher risk. Generally two typical types of measuring techniques are quite popular like Direct Reading (DR) and Analytical Ferrography. But in the present work, direct reading ferrography has been utilized as the operational mode. With the help of the DR instrument, the density of large particles (D_L) and the density of small particles (D_S) can be measured very easily. On the basis of those parameters, the values for wear particle concentrations and the percentages of large particles can be detected. Figure4 and Figure5 show the DR instrument with its general deposition of particles. By performing quantitative analysis of wear particles, the possible mode of wear generation can be detected. Based on the detection of wear, the further course of action for maintenance of equipments can take place [5].

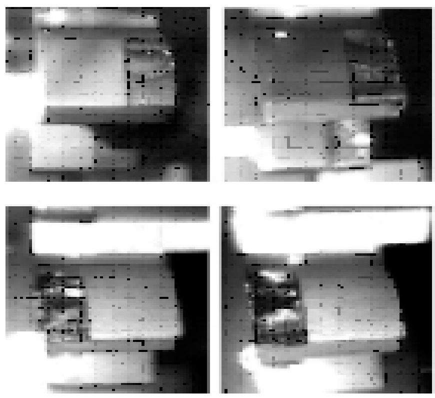

Figure 3: Probable damages in gear tooth.

The number of wear particles can be mathematically deduced by using the relationship,

Severity Index (S.I.) = $(D_L + D_S)(D_L - D_S) = (D_L^2 - D_S^2)$

Where D_L = Number of larger particles, D_S = Number of smaller particles, $D_L + D_S$ = Concentration of solution,

$D_L - D_S$ = Size distribution.

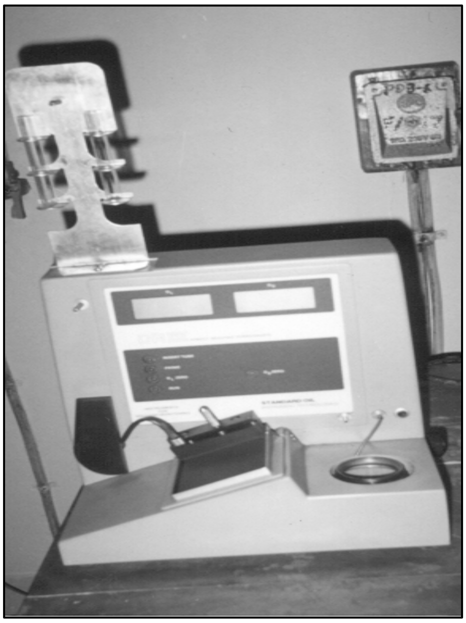

Figure 4: DRIII system for wear separation.

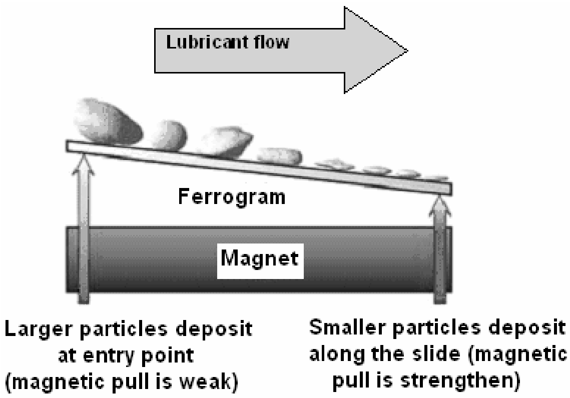

Figure 5: Particles deposition in the ferrograms.

Based on quantitative analysis, qualitative analysis can also be done by using Dual Ferroanalyzer as shown in Figure6. It is basically the ferrogram making instrument, where dual slide makers are available.

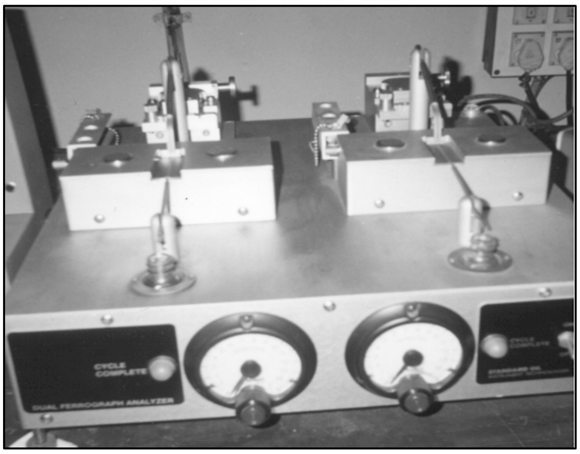

Figure 6 : Dual ferroanalyzer for ferrogram preparation.

It should be used with maximum equipment utilization in wear analysis [5]. For better handling, independent places have been provided where two samples can be prepared concurrently. In the present work, the ferrograms of used oil from gearbox have been prepared by this instrument.

4. Fractal Mathematics Application

Fractal dimension is the technique of quantifying the degree of ruggedness of highly irregular objects. Fractal objects can be found everywhere in the nature like, trees, ferns, clouds, snowflakes, mountains, bacteria, coastlines, and etc. It is very useful in characterizing the roughness of wear debris for machine condition monitoring [6]. Benoit Mandelbrot has proposed this concept in mid 70s. Finding the fractal of any object is quite very important to know about concepts like, self-similarity, chaos and non-integer fractal dimension (FD). Mathematically fractal can be defined as,

$$FD = \lim_{r \to 0} \frac{\ln N}{\ln[\frac{1}{r}]} \quad (1)$$

Where, N = number of self-similar pieces and = magnification factor

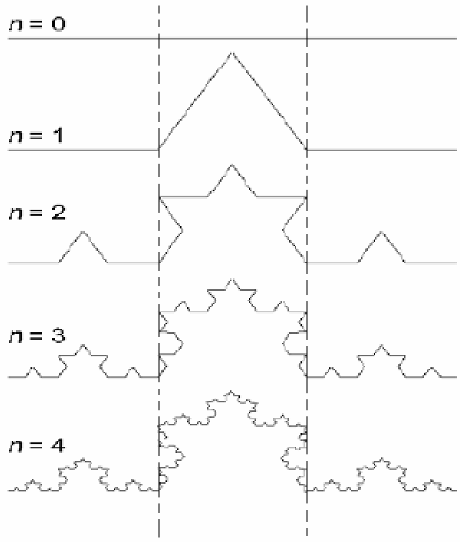

Figure 7: Fractal dimension considering Koch Curve.

In Koch Curve, N = 4, r = 1/3
Hence, FD = (ln 4) / (ln 3) = 1.261
Fractal dimension can also be interpreted by Mandelbrot's method as shown in Figure 8.

Apart from the traditional fractal concepts, EXACT, FAENA, FAST, and etc., algorithms are also quite effective in any imaging techniques. Basically, these kinds of algorithms are computer implementation of Richardson Plot as shown in Figure9.

In this work, FAST algorithm has been applied to minimize calculation hazards [6]. In this algorithm, the step size can be considered as a number of boundary pixels, and the step length may be taken as the Euclidean distance between end points of the predetermined step size. The start and end pixels of the step size are connected by a straight line, and the real particle boundary is approximated by a polygon. After completion of each round, the step lengthens, i.e. the lengths of straight line can be added to each other. The average step length can be calculated by dividing the sum of the step lengths by the number of straight line segments in the polygon.

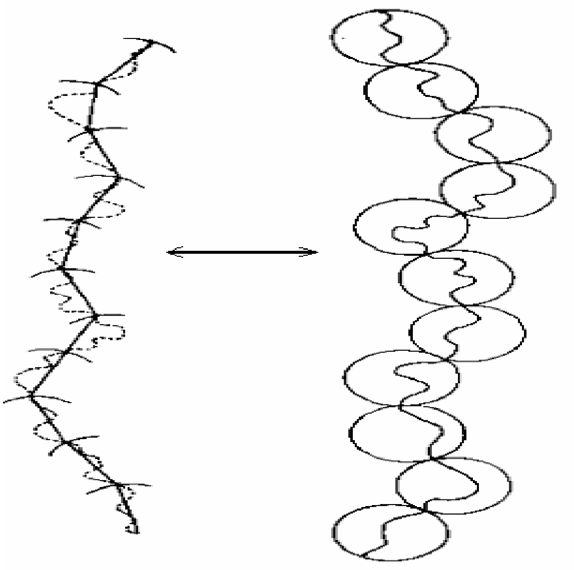

Figure 8: Fractal dimension by Mandelbrot's method.

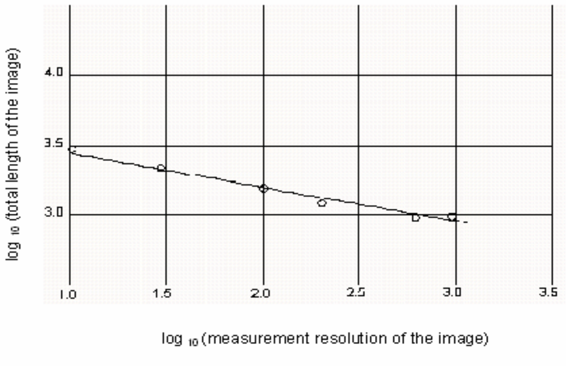

Figure 9: Richardson plot.

The perimeter of the polygon can be calculated by adding the final incomplete step length to the sum of the other step lengths. In this way, the process can be repeated at various step sizes [7]. After that, the perimeter lengths vs. step lengths should be plotted on a log-log scale graphs, and from the plot, fractal dimension can be calculated by using the relationship,

$$FD = 1 - m \quad (2)$$

Where, m = slope of the best fitted line of the log (step length) vs. log (perimeter) plot.

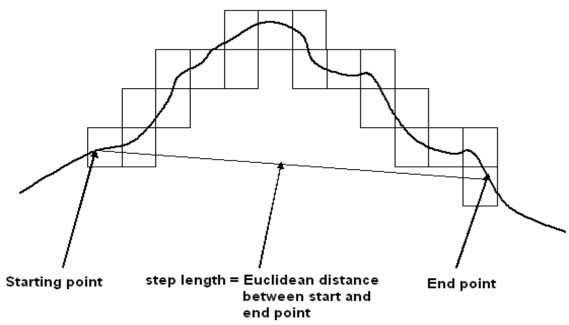

Figure 10: FAST method.

5. Fuzzy Inference System

Fuzzy logic is a logical system, which is an extension of multi-valued logic. But in a broader sense, it is related to the theory of fuzzy sets where the theory relates to classes of objects with non-sharp boundaries in which membership is a matter of degree [8].

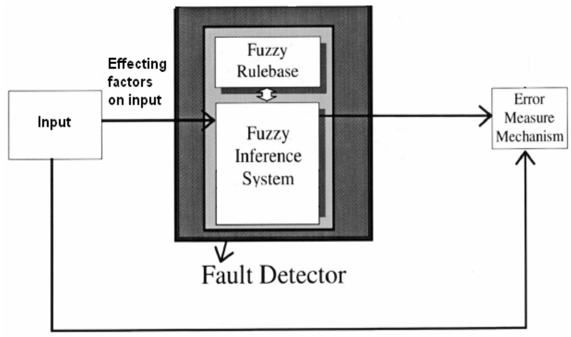

Figure 11: Fuzzy inference structure.

Membership function (MF) in fuzzy inference system is the vital part where a curve that defines how each point in the input space is mapped to a membership value, or degree of membership between '0' and '1' has been graphically interpreted in Figure12.

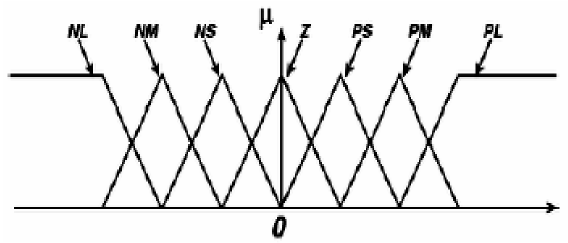

Figure 12: Membership functions for the set of all numbers.

(N = Negative, P = Positive, L = Large, M = Medium, S = Small)

Basically, two types of inference systems have been found for structuring any system, i.e. Mamdani and Sugeno methods. Both techniques are quite efficient to form any inference system, but Mamdani has been used in the present work. In the present work, different rules have been established and have been applied in proper maintenance planning at offline stage of operation.

6. Case Study

The work concentrated mainly on the monitoring strategy of gearbox of rolling mill where condition monitoring through wear analysis has been done. The medium was used oil; and has been collected from the gearbox of cold rolling mill in a reputed industry nearby Kolkata, India. The application of monitoring techniques has a wide range, but in the present work gearbox has been considered as the case study, where the periodic observations took 14-15 days, and depending on that, soft computational strategies have been applied. DRIII ferrograph along with dual ferroanalyzer and color CCD camera mounted on microscope has been utilized in the present work [9]. The entire work has been segmented into different stages, which is shown in Figure13.

The specification of DRIII ferrograph has been considered as indicated by the manual of “Wear Particle Atlas (WPA), Standard Oil Corporation Limited, USA”.

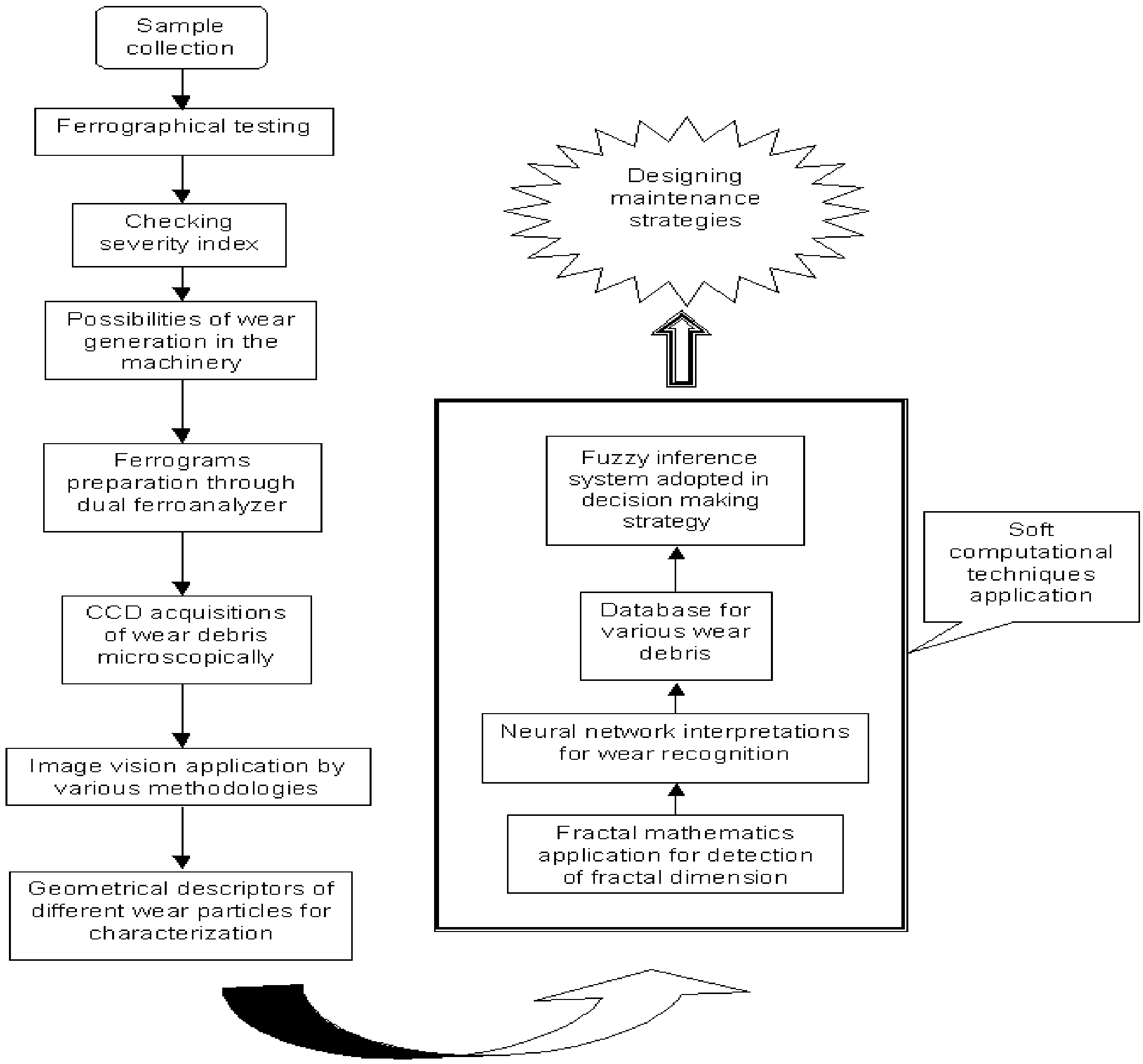

Figure 13: Steps involved in the entire work..

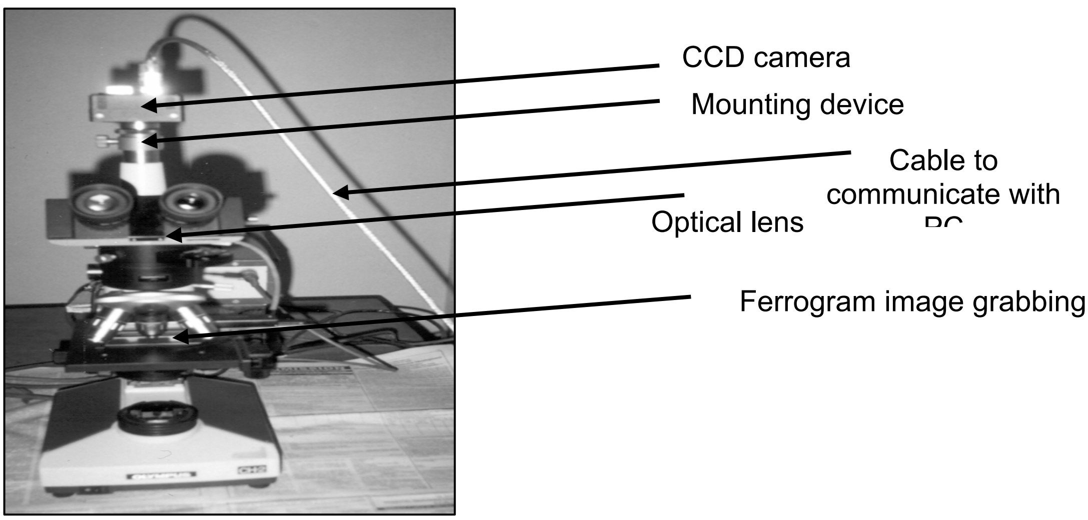

Figure 14: Microscope with CCD camera for image processing of particles.

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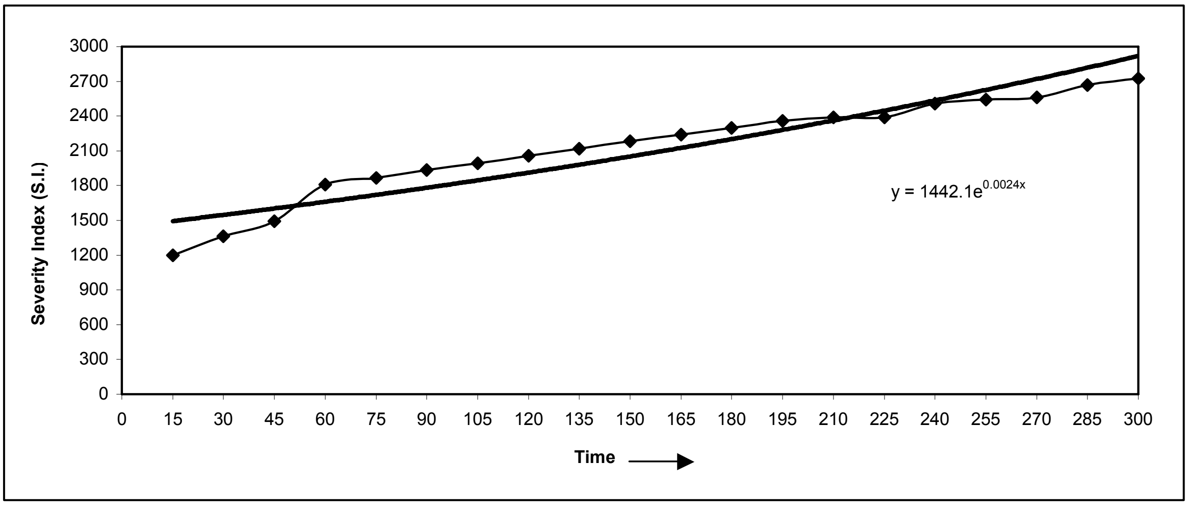


Figure 15: Nature of severity index for gearing system.

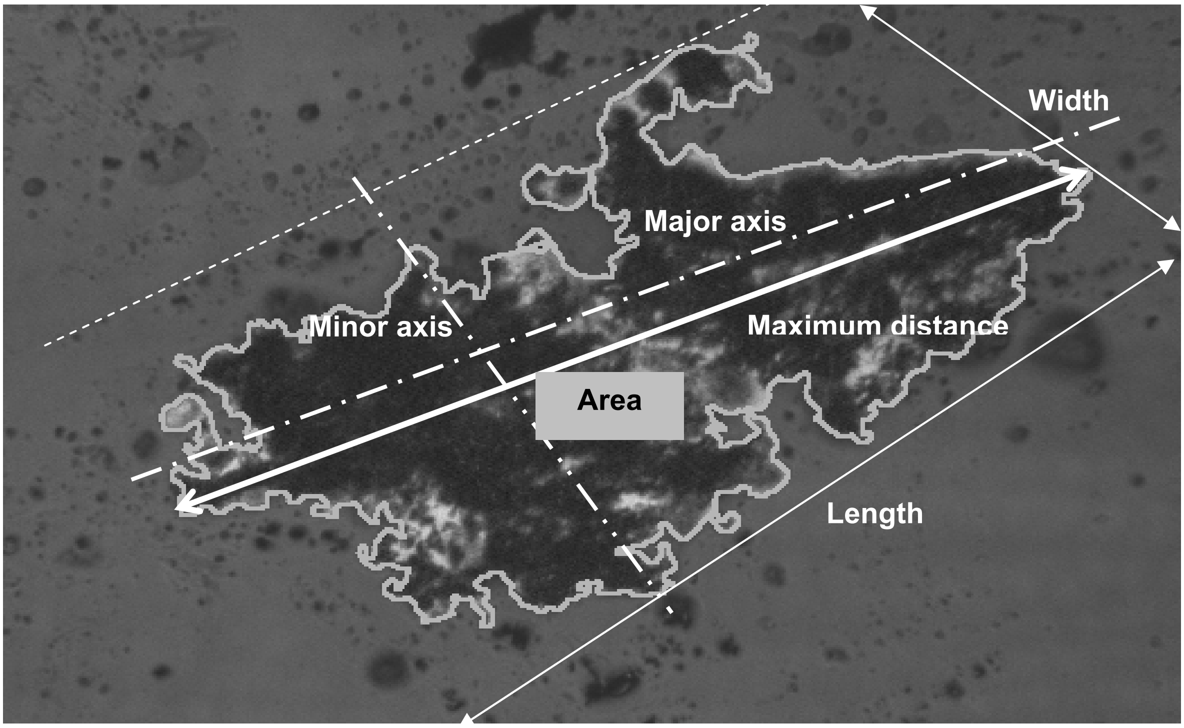


Figure 16: Geometrical parameters projected on wear image.

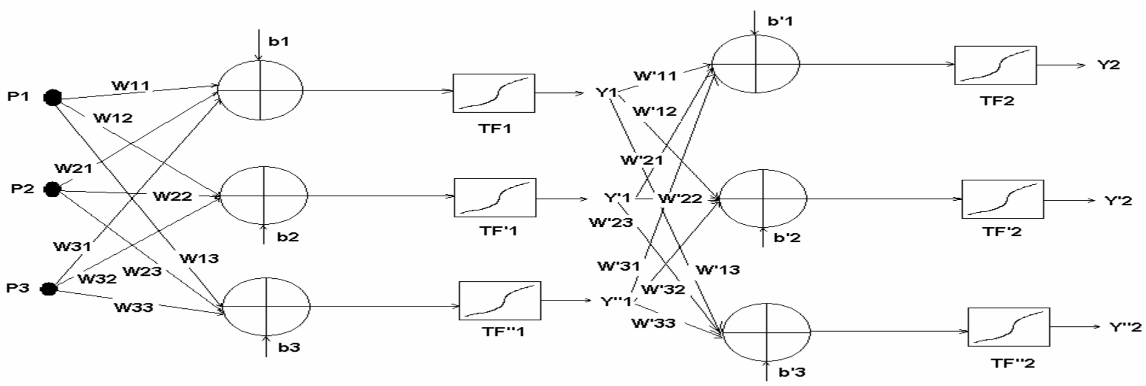


Figure 17: Neural structure for the present work..

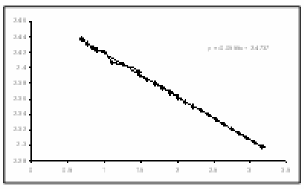
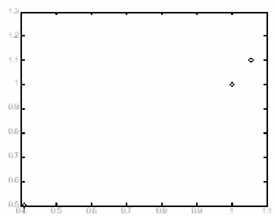
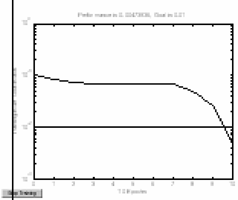
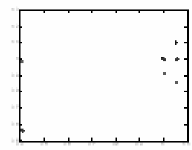
Table 1: Severity index (S.I.) formulation for gearing system of rolling mill.

Length of step (LOS)	log (LOS)	Perimeter (P)	log (P)
6	0.778	270.19	2.431
7	0.845	266.69	2.426
8	0.903	265.38	2.423
10	1	263.17	2.42
13	1.113	255.65	2.407
18	1.255	253.56	2.404
31	1.491	248.64	2.395
26	1.483	246.28	2.391
29	1.588	242.75	2.385
32	1.694	239.23	2.38
36	1.799	235.7	2.374
39	1.904	232.17	2.368
42	2.009	228.64	2.362
45	2.115	225.11	2.356
48	2.22	221.58	2.35
51	2.325	218.05	2.345
54	2.43	214.52	2.339
57	2.535	210.99	2.333
61	2.641	207.47	2.327
64	2.746	203.94	2.321
67	2.851	200.41	2.316
70	2.956	196.88	2.31
73	3.061	193.35	2.304
76	3.167	189.82	2.298

Table 2-a : Wear recognition techniques by fractal dimension Estimation.

Sl. No.	DL	Ds	S.I. = DL2 – DS2
1.	41.60	23.10	1196.95
2.	42.10	20.20	1364.37
3.	41.00	13.70	1493.31
4.	44.00	11.20	1810.56
5.	43.70	6.500	1867.44
6.	44.31	5.280	1935.50
7.	44.92	4.940	1993.40
8.	45.53	4.160	2055.68
9.	46.14	3.380	2117.47
10.	46.75	1.600	2183.00
11.	47.36	1.650	2240.24
12.	47.97	1.580	2298.62
13.	48.58	1.510	2357.74
14.	48.89	1.460	2388.09
15.	48.91	1.410	2390.20
16.	50.11	1.310	2509.29
17.	50.42	1.320	2540.43
18.	50.63	1.250	2561.83
19.	51.65	1.220	2666.23
20.	52.21	1.190	2724.46

Table 2-b: Wear recognition techniques by fractal dimension estimation.

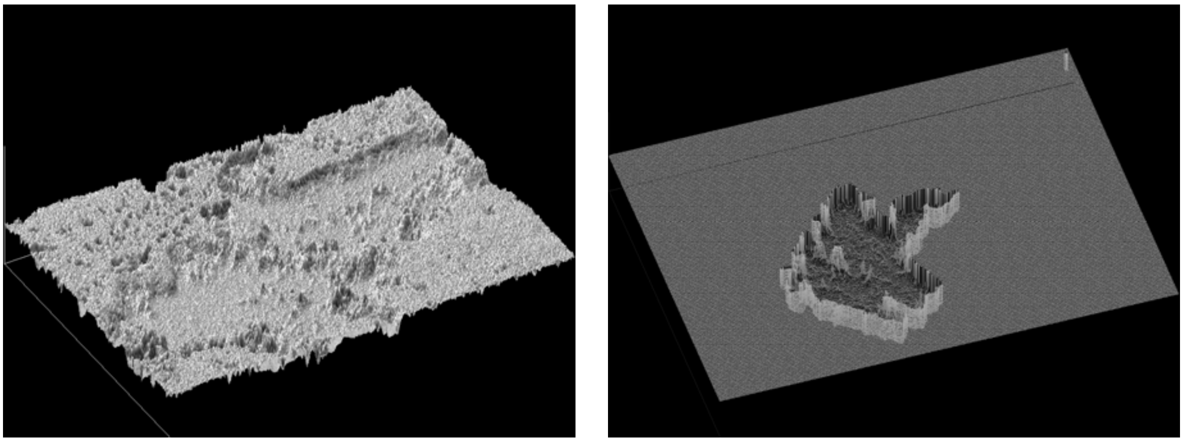
Fractal Dimension estimation	Plot between input vs. target	Training outcomes	Plot between input vs. final output
 Area (A) = 5667.913, Roundness (R) = 1.531, Length (L) = 68.654, Breadth (B) = 82.412, Aspect Ratio (AR) = 0.833, Shape Factor (SF) = 0.653, Dispersion of the Image (DP) = 14.114, FD = 1.0555	 Input vector for the processed image (FD, color, shape) = 1.0555, 0.409, 1 Target vector for network (FD, color, shape) = 1.06, 0.5, 1		 Type of wear = Rubbing Wear

[Note: R = (4 x area) / π .(length)^2, AR = (length / width) of the image, SF = $\log_2(AR)$, DP = $\log_2(\pi LB)$ All dimensions have been taken in µmm.

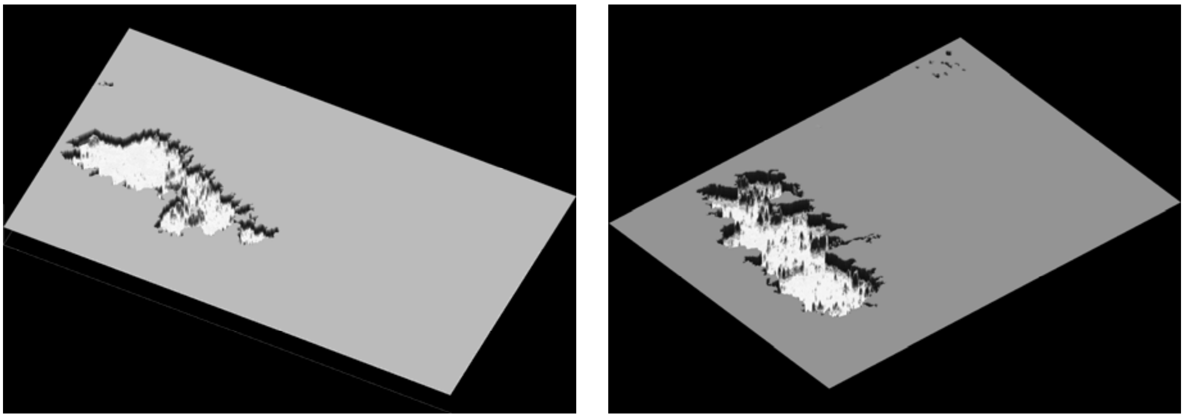
Figure 4, Figure 6, and Figure 14 show the instrumental setup for the experimentation of the present work. After performing the ferrographical testing, the results and severity index (SI) have been checked out properly. In the first stage, the used oil has been collected for testing. In the second stage, the sample has been kept in the ferrograms through ferroanalyzer. In the last stage, the microscopic analysis of wear images has been experimented through color CCD camera [10, 11]. After these stages, the soft computing methodologies have been adopted for explanatory decision making. The entire work has been performed at offline stage to avoid the experimentation hazards, though it can be applied in online stage by building up a knowledgebase system. The severity index has been calculated in the present case of the rolling system (Table 1). Accordingly, the nature of severity has been indicated in Figure15. The actual projection of any wear image has been used in a particular scale (Figure16).

Some of the numerical descriptors have been calculated based on which maintenance strategy has been taken up in this research work [12, 13]. In the present work the backpropagation neural net has been used, which as given in Figure 17.

After the image being recognized, the fuzzy inference system has been applied to reach at a decision making policy of maintenance of the machinery[5].



(a)



(b)

Figure 18: Surface textures of wear images at different angles, a, b.

In fuzzy system, mainly FD, shape and color of the images have been considered as input vector for decision making planning. The basic strategy of the present system has been given in Table-2, where the type of wear recognized as rubbingwear based on which strategy of the maintenance has been considered successfully.

7. Conclusion

The purpose of the present work was to investigate the scope of application domain of soft computing methodologies in automated analysis of various wear mechanisms at the used lubricants of the industrial machineries in offline monitoring process. Mainly, the ferrographical testing of used oil has been performed in the present work and through microscopic view of various wear particles that were generated in machine components where the automated analysis has been performed. But in present work, the usability of fractal mathematics in the particles geometry has been strongly estimated though main emphasis has been given to the neural network. Basically, ANN has been applied for recognition purpose. Amongst other techniques of ANN, back propagation was used to minimize calculation hazards. The proposed methodology is one of the approaches that can be adopted by various organizations, but it can be continued further at online monitoring process by considering the fuzzy concept, too. So that an entire knowledge base system can be prepared. The cost and time factors both can be adjusted by utilizing such kind of system on the field of machine condition monitoring.

Acknowledgement

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APPENDIX-A

Pseudo Code for the present work

```
INPUT
        FRACTAL DIMENSION = FD
        COLOUR = C
        SHAPE = S
        MAINTENANCE STRATEGY = MS

IF
        FD = 1.0625
        C = 0.562
        S = 1
THEN
        MS = “Improve the Lubricating Medium”
ELSE
        MS = “Carry on the Regular Maintenance”
```

[This is one example related to the proposed methodology. But this has been applied in different values of the input vectors for various wear particles to get the proper maintenance strategy]

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Electricity Consumption in the Industrial Sector of Jordan: Application of Multivariate Linear Regression and Adaptive Neuro-Fuzzy Techniques

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Abstract

In this study two techniques, for modeling electricity consumption of the Jordanian industrial sector, are presented: (i) multivariate linear regression and (ii) neuro-fuzzy models. Electricity consumption is modeled as function of different variables such as number of establishments, number of employees, electricity tariff, prevailing fuel prices, production outputs, capacity utilizations, and structural effects. It was found that industrial production and capacity utilization are the most important variables that have significant effect on electrical power demand. The results showed that both the multivariate linear regression and neuro-fuzzy models are generally comparable and can be used adequately to simulate industrial electricity consumption. However, comparison that is based on the square root average squared error of data suggests that the neuro-fuzzy model performs slightly better for prediction of electricity consumption than the multivariate linear regression model.

Keywords: Industrial sector; electricity consumption; modeling; multivariate regression; neuro-fuzzy

1. Introduction

Jordan is considered among low-middle income countries, within the Middle East Region, with an average income per capita of about US$ 2,770, in 2007, and its population reached 5.723 million inhabitants [1]. It suffers from a chronic lack of adequate supplies of natural resources including fresh water, crude oil and other commercial minerals. Thus, Jordan depends heavily on imports of crude oil, refined products and natural gas from neighboring Arab countries as main sources of energy. Its current imports of around 100,000 barrels of crude oil per day are placing the country under extreme economic pressures, especially with increasing unit price of oil in the international market. The annual energy bill has been rapidly increasing over the past few years due to high rates of population and economic growth combined with the consecutive increase in oil price. Consequently, there has been a growing concern about energy consumption and its adverse impact on the economy and environment, with special focus on the industrial sector, because its contribution accounted for about one third of final energy and electricity consumption.

The industrial sector was probably affected the most by the economic and technological changes that the country has witnessed during the past three decades. For example, in 1985, there were about 4,546 industrial facilities and workshops, and 43,313 employees [2]. Two decades later, the industrial sector has grown to include about 13,357 facilities and employed approximately 150 thousand workers, most of them are Jordanians [3]. Such enormous increase in the number of facilities and produced products has contributed to an increase on energy and electricity demands. In 2007, electricity consumption reached nearly 10,553 GWh with shares of 29, 36, 16, 15, 2, and 2% for industrial, residential, commercial sectors, water pumping, street light, and for other purposes (such as agricultural sector) respectively (Ministry of Energy and Mineral Resources [4].

Energy modeling is a subject of widespread current interest among engineers and scientists concerned with problems of energy supply and demand in different sectors of the economy [5-11]. It is a tool that has capability of making useful contributions to planning and future policy formulation of energy sector [12]. In spite of the existence of several studies attempting to analyze current and future energy requirements for different sectors and industries in Jordan [13-16], there is still a need for more detailed studies and tailor-made models to analyze and explain driving forces behind changes in electricity consumption in the industrial sector and other sectors of the economy. Therefore, this paper will use statistical and artificial intelligence methods to simulate and identify main drivers behind growth in electricity consumption in the Jordanian industrial sector in order to support the on-going and future energy-related research aiming to improve the general situation and efficiency of this sector. Such a model would help energy planners to understand the implications of changes in the exogenous variables when

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underlying relationships are fairly stable; this would be of great help in designing better national energy policies and strategies.

Traditionally, regression analysis has been the most popular modeling technique in predicting energy consumption [5-7, 9, 17-18]. Recently, with the rapid development of data modeling, alternative approaches such as neural networks and neuro-fuzzy methods have become more popular and easier to operate in different areas [19-20]. However, their applications, especially the neuro-fuzzy method, are rarely explored in forecasting and/or analysis of energy consumption. This study demonstrates and compares the application of multivariate regression and neuro-fuzzy models in predicting electricity consumption in industry in Jordan.

This paper was organized in four sections, including the introduction. The methodology adopted, in this study, is described in the following section, results and discussions are presented in section three, and the paper ends with some concluding remarks.

2. Methodology

Several models have been previously proposed to model electricity and energy consumptions, ranging from relatively simple ones, such as that proposed by Al-Shehri [21] which consists of only a single equation model for industrial energy consumption, to more complex models, such as that developed by the Energy Information Administration (EIA) [22] which consists of several modules that interact with each other through an integration module. A survey of energy consumption models can be found in [23-24]. This study will use the analysis of variance (ANOVA) that is based on least square method to identify the most important variables that affect electricity consumption of the industrial sector. The key variables will then be utilized to develop different models that are based on multivariate linear regression and neuro-fuzzy analyses.

2.1. Variables

In the open literature, previous research papers have taken into consideration variables such as energy costs, production levels, number of employees, and number of establishments [17, 25]. This study utilizes advantages of such experience and introduces other new important variables such as structural effect and the capacity utilization factor. These variables are briefly explained in the following section, along with reasons for their inclusion in the current proposed model.

2.1.1. Structural Effect (G_I/G_N)

At a given level of output, as demand changes towards more electricity-intensive industries, electricity demand will rise accordingly. In contrast, a shift towards less electricity-intensive industries would have an opposite effect: causing net reduction on final electricity consumption. To capture this effect in the model, the manufacturing sector is disaggregated into two industrial clusters: electricity intensive (G_I) and non-electricity intensive (G_N) clusters. The ratio between the gross outputs of these two clusters is included as a variable in this model.

2.1.2. Electricity Prices (E$)

When the unit price of electricity is increased, the industry is expected to respond by using electricity more efficiently, i.e. by applying energy conservation and management measures.

2.1.3. Fuel Prices (F$)

At present diesel and heavy fuel oil (HFO) are the most common substitutes for electricity in most industries, in Jordan, especially for manufacturing processes such as heating and drying applications. It is worth noting that neither imported nor locally produced natural gas is available, yet, for industry. It is expected that when diesel and HFO prices are increased, most industries will respond by switching to electricity and vice versa. The weighted average of diesel and HFO prices is included in the current model.

2.1.4. Establishments (ES)

Since each facility consumes certain amount of electricity to enable its production, as the number of facilities increases, industrial electricity consumption is expected to increase.

2.1.5. Capacity Utilization (CU)

This variable represents how efficiently industrial establishments will utilize the installed production capacity. This variable is included in this study simply because as capacity utilization factor increases, the available resources, including electricity and energy, are employed more efficiently. Furthermore, as final production increased, then losses per unit produced would be much less.

2.1.6. Number of Employees (EM)

This variable can be viewed from two different perspectives. To some degree, technology has replaced human labor in the majority of industries, and therefore electricity consumption may increase due to the increased on automated production lines and systems. On the other hand, each employee requires additional electricity in the form of conditioned air, hot water, lighting, etc., and thus electricity consumption would decrease as modern machines replace old fashioned manually operated ones.

2.1.7. Gross output (G)

A wide range of products are manufactured, in Jordan, ranging from food products to chemical and mining industries. Therefore, it is extremely difficult to rely on the physical products to indicate the production level. For this reason, the monetary value of goods is used instead of the number of goods in this investigation. Thus, it is expected that the total value of final products will have a proportional relationship with electricity consumption in the industrial sector: higher monetary value of products would require greater rates of electricity consumption in order to be generated.

2.2. Data Sources

Historical data, during the period 1985-2004, are utilized to build the current simulation model for electricity consumption in the industrial sector. Electricity consumption data were obtained from the Ministry of Energy and Mineral Resources (MEMR) online database

[26]. Economy data such as gross output, number of establishments and employees were taken from annual statistical reports by the Department of Statistics [27]. Electricity tariff, which shows the current structure and prices of unit of electricity for different groups of consumers, was taken from published annual reports of different governmental institutions [28-29].

Fuel prices were taken from annual reports of MEMR [30]. Other required data about structural effect and capacity utilization variables are not available directly, but have been estimated in a previous research paper [7]. As mentioned previously, there are two clusters of industries in Jordan, i.e. (i) the electricity-intensive industries include mining and quarrying, textiles, papers, basic metals, plastics, and chemical industries, and (ii) non-electricity-intensive industries include all other industries in the manufacturing sector. Knowing this, the ratio between the gross outputs of these two clusters (G_I/G_N) can be determined.

In Jordan, unfortunately, no information is available regarding capacity utilization of different industries; therefore, the following analysis is adopted in this study to estimate the relative capacity utilization from one year to another: for a given industry, the ratio of total gross output to the number of facilities within the industry has been calculated for each year (during the study period from 1985 to 2004). The maximum ratio is taken as an indication of maximum capacity utilization and is given a value of one. The capacity utilizations for the remaining years are then calculated relative to the obtained maximum ratio, by dividing the ratio obtained for a given year to the maximum ratio. This analysis has been carried out for all industries, then the overall industrial sector capacity utilization has been calculated as a weighted average of capacity utilization for all industries within the industrial sector. Table 1 shows the complete set of data used in this research.

Table 1: Data set for the Jordanian industrial sector electricity consumption model.

Year	E (TJ)	G_I/G_N	E$ (JD/TJ)	F$ (JD/TJ)	ES	CU (%)	EM	G (10^3 JD)
1985	3,251	0.42	7,553	1,771	4,546	39.00	43,313	952,231
1986	3,262	0.33	6,874	1,744	4,871	33.40	40,529	786,734
1987	3,820	0.33	6,234	1,593	5,088	29.00	41,824	870,660
1988	3,744	0.40	6,121	1,630	5,192	38.70	41,647	990,026
1989	3,949	0.49	5,889	2,002	5,603	52.90	48,791	1,322,170
1990	4,277	0.45	7,804	2,001	6,221	55.70	51,617	1,454,955
1991	4,252	0.44	7,828	2,008	8,123	55.00	57,434	1,543,584
1992	4,831	0.35	8,692	2,445	9,367	63.60	70,393	2,084,846
1993	5,141	0.30	8,700	2,531	9,049	58.90	71,413	2,063,737
1994	5,468	0.28	8,665	2,556	8,649	66.00	99,660	2,493,167
1995	6,008	0.29	8,628	2,587	8,979	68.30	103,176	2,792,184
1996	6,383	0.31	10,112	2,589	8,951	63.40	106,437	2,784,456
1997	6,476	0.30	10,095	2,590	8,970	67.10	108,219	2,935,171
1998	6,847	0.29	10,079	2,636	9,039	65.90	110,229	3,058,377
1999	6,894	0.31	10,094	2,641	10,610	63.10	116,061	3,096,897
2000	7,106	0.27	10,094	2,645	11,504	60.30	123,348	3,167,108
2001	7,286	0.28	10,111	2,908	12,055	65.00	130,296	3,404,568
2002	7,895	0.26	10,372	3,114	12,489	70.10	136,653	3,699,853
2003	8,316	0.25	10,644	3,458	12,923	72.00	143,010	3,884,816
2004	8,924	0.24	10,687	3,648	13,357	87.60	149,367	4,902,862

2.3. Multivariate Linear Regression Model

Regression analysis is widely used to analyze multifactor data by building appropriate mathematical equation that relates the response (i.e. variable of interest) to a set of predictor or independent variables, as shown in Equation 1 which is the proposed multivariate linear regression model. The starting point of this analysis is to define the response variable (here it is electricityconsumption in the industrial sector) and the important factors (here these are the structural effects, electricity and fuel prices, number of establishments,capacity utilizations, number of employees, and production outputs) that might be relevant to explain the response's behavior.

$$(E)_t = \mu_0 + \mu_{I,N}(\frac{G_I}{G_N})_t + \mu_1(E\$)_t + \mu_2(F\$) + \mu_3(ES)_t + \mu_4(CU)_t + \mu_5(EM)_t + \mu_6(G)_t + \varepsilon_t \quad (1)$$

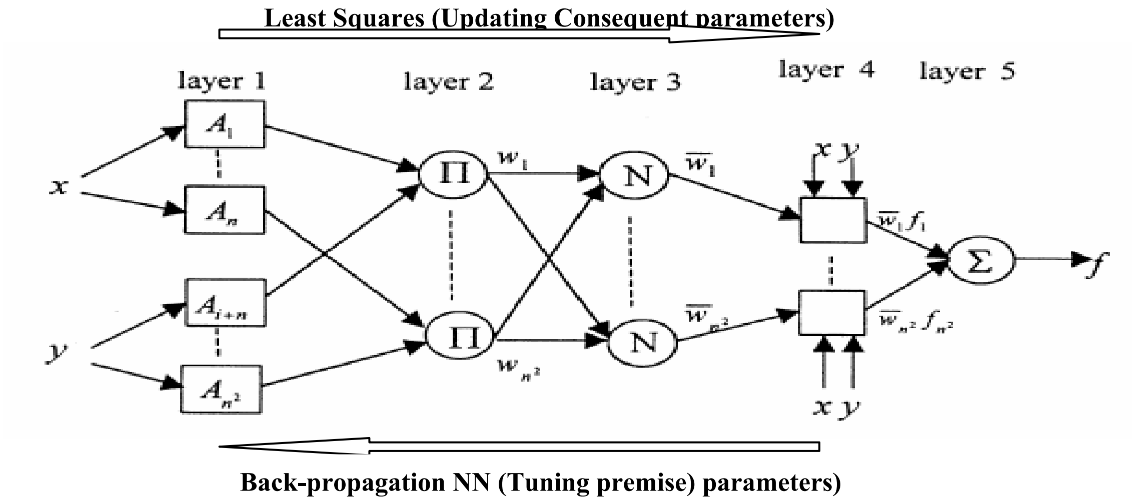


Figure 1: ANFIS Architecture [31].

where E is the electricity consumption, μ_0 the regression model intercept, $\mu_{I,N}$ the regression model coefficient of the gross output ratio between the outputs of intensive (I) and non intensive (N) industrial clusters, μ_j represent the regression model coefficients (j = 1,2,3,4,5, 6), t represents the year t, and ε_t the difference between the actual and the predicted electricity consumption.

2.4. Adaptive Neuro-Fuzzy Model

Neuro-fuzzy is an associative memory system that consists of fuzzy nodes instead of simple input and output nodes, and it uses neural network learning functions to refine each part of the fuzzy knowledge separately.

Learning in a separated network is faster than learning in a whole network [31]. An adaptive neuro-fuzzy inference system (ANFIS) is a fuzzy inference system implemented in the framework of an adaptive neural network. By using a hybrid learning procedure, ANFIS can construct an input-output mapping based on both human-knowledge as fuzzy If-Then rules and stipulated input-output data pairs for neural networks training. ANFIS architecture is shown in Figure 1, where x and y are the inputs, f is the output, A_i and A^2_n are the input membership functions, w_i and w^2_n are the rules firing strengths.

ANFIS is an architecture which is functionally equivalent to a Sugeno-type fuzzy rule base. It is a method for tuning an existing rule base with a learning algorithm based on a collection of training data. This allows the rule base to adapt. Training data is used to teach the neuro-fuzzy system by adapting its parameters (which in essence are fuzzy set membership function parameters) and using a standard neural network algorithm which utilizes a gradient search, such that the mean square output error is minimized. From the ANFIS architecture, shown in Figure 1, it is observed that for given values of premise parameters, the overall output can be expressed as a linear combination of the consequent parameters.

ANFIS modeling and prediction of electricity consumption starts by obtaining a data set (input-output data points) and dividing it into training and validating data sets. The training data set is used to find the initial premise parameters for the membership functions by equally spacing each of the membership functions. A threshold value for error between the actual and desired output is determined. The consequent parameters are computed using the least squares method. Then, an error for each data pairs is found. If this error is larger than the threshold value, the premise parameters are updated using the back propagation neural networks. This process is terminated when the error becomes less than the threshold value. Then, the testing data points are used to compare the model with actual system for validating purposes. Figure 2 shows the ANFIS training and modeling process.

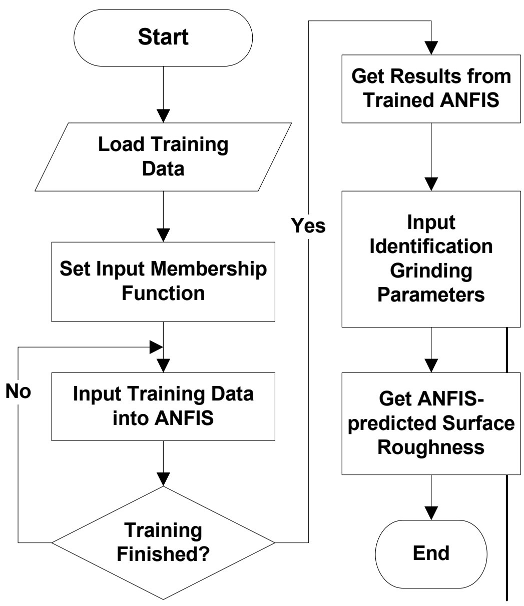


Figure 2: ANFIS Flow chart.

After identifying the most important variables using ANOVA, five models of different data sets were developed using the multivariate linear regression analysis. The same data set is then utilized to develop another five models using the neuro-fuzzy analysis. Each data set is obtained by randomly dividing the whole data into two groups: training group which is used to build the model and testing group which is used to validate the model. The square root of average squared error (*RASE*) of testing group, given by Equation 2 [32], is used as performance measure in the comparison process between the multivariate linear regression and neuro-fuzzy models.

$$RASE = \sqrt{ASE} = \sqrt{SSE / n} \quad (2)$$

$$SSE = \sum_{i=1}^{n} (E - \hat{E})_i \quad (3)$$

Where *SSE* is the sum of squared error, *n* the number of observations of testing group, *E* the actual electricity consumption, $\hat{E}$ the predicted electricity consumption, and *ASE* the average squared error.

3. Results and Discussions

3.1. Variable Selection

A software package (Minitab) is applied to test the significance of each variable described before using the least square method (the ANOVA analysis). Table 2 shows the ANOVA results. In order to decide whether or not a variable is significant, the *p-value* associated with each parameter has been estimated and is provided in the same table. In this study, the variable that has a p-value smaller than 0.05 is considered as an important variable. Therefore, electricity unit price, fuel prices, number of establishments, number of employees, and the structural effect variables were not significant at the 0.05 level.

Table 2: ANOVA results For the Jordanian Industrial electricity Model

Variable*	Coefficient	*P*-value
Intercept (TJ)	3731.0	0.000
(G_I/G_N)	471.1	0.605
E$(JD/TJ)	-0.06649	0.286
F$ (JD/TJ)	0.0119	0.968
*E*S	0.01396	0.750
CU (%)	-48.108	0.000
EM	-0.02248	0.055
G (1000 JD)	0.0030649	0.000

Note: *: R^2= 99.6%, Adjusted R^2= 99.3%, Predicted R^2= 98.55%.

3.2. Multivariate Linear Regression Analysis

Five models have been built but now using only the significant variables; i.e., the gross output and capacity utilization factor. In each model, fourteen data points have been selected randomly to build the model. Table 4 summarizes obtained results of the five models.

3.2.1. Model Adequacy Check

In order to verify the multivariate linear regression model, its adequacy should be checked.

First of all, the ANOVA tool, used in the multivariate linear regression analysis to test the validity and significance of the model, is based on some assumptions, such as the residuals having constant variance and being normally distributed. A graphical analysis of the residuals can be used to check the validity of such assumptions [33]. Figure 3 (a) and (b) shows the residual plots of one of the previous five models. As can be seen from this figure, the analysis demonstrates satisfactory results since the residuals are contained within a horizontal band (the constant variance assumption is satisfied) and since the cumulative normal distribution is approximately a straight line (i.e. the normality assumption is also satisfied). The residual analysis for the remaining four models demonstrates also satisfactory results. Secondly, no leverage and influence points were detected in all models. Thirdly, larger *variation inflation factors (VIFs)*, usually larger than 10 [33], indicate that the associated regression coefficients are poorly estimated because of multicollinearity. The later suggests near-linear dependencies among the regression variables. As can be shown from Table 3, the variation inflation factor (*VIF*) for the parameters is less than 10; this is an indication that multicollinearity does not exist in these models. Fourthly, each model seems to represent its data's behavior acceptably since most popular measures of goodness-of-fit are satisfied, i.e. the coefficient of multiple determination (R^2), the adjusted R^2, and the predicted R^2 statistics are very high for all models as can be seen from Table 3. Finally, all coefficients in five models have the expected signs, and their magnitudes seem to be reasonable. From the preceding tests, one can conclude that each suggested model does not violate main assumptions, and represents its data accurately.

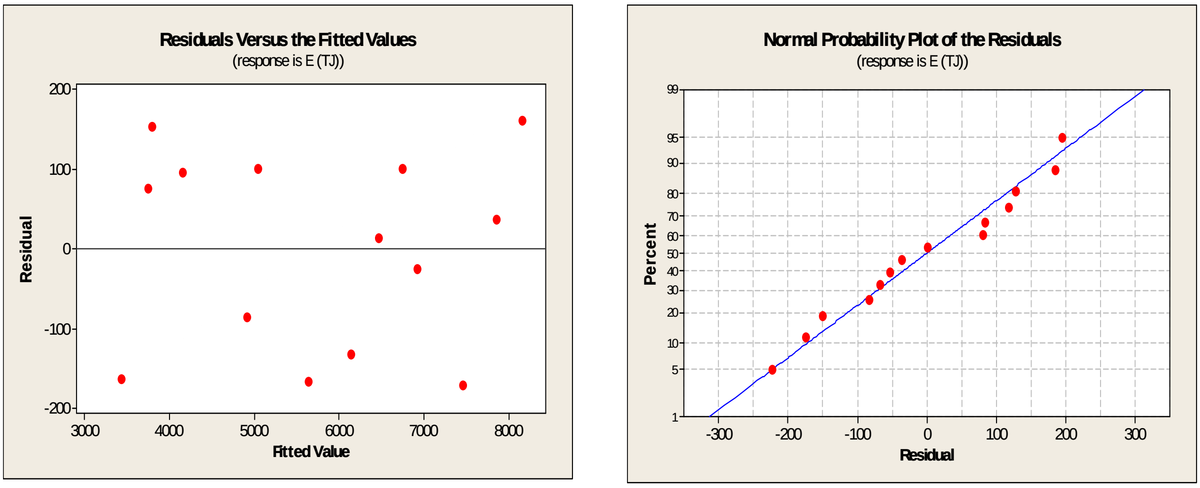
3.3. Adaptive Neuro-Fuzzy Analysis

The fuzzy logic toolbox of Matlab 7 was used to obtain deemed results. A total of 26 nodes and 8 fuzzy rules were used to build the fuzzy systems for modeling the Jordanian industrial electricity consumption.

3.3.1. ANFIS Prediction Of Electricity Energy Consumption

The five data sets, mentioned previously, are now used to build another five models that are based on neuro-fuzzy analysis. Following is the results for one of these models. The neural network training for building a fuzzy model for electricity consumption used 14 training data points, and 800 learning epochs. Figure 4 shows the training curve of ANFIS with root mean square error (RMSE) of 23.5 (i.e., almost 0.5%). A comparison between the actual and ANFIS predicted electricity consumption values after training is shown in Figure 5, which shows that the system is well-trained to model the actual electrical energy consumption. The ANFIS-predicted electricity consumption is shown in Figure 6 as a surface plot of electricity consumption as a function of the gross output (G) and capacity utilization (CU).

[1] In this model and all following models, years 1990 and 2004 were deleted from the model since they have large residuals, even after some data transformation and centering.



(a) (b)

Figure 3: (a) Residual versus fitted values and (b) Normal probability plot, for the Jordanian industrial electrical model.

Table 3: Regression Summary Outputs for the Jordanian Industrial electricity Models

Coefficient**	Model 1	Model 2	Model 3	Model 4	Model 5
Intercept (TJ)	2952.4	3067.2	3049.2	2938.8	2859.2
CU (%)+	-34.062 [6.0]	-34.526 [6.4]	-34.924 [4.5]	-32.483 [5.6]	-32.457 [5.5]
G (1000 JD)	0.00197417 [6.0]	0.0019493 [6.4]	0.00196125 [4.5]	0.00194147 [5.6]	0.00197580 [5.5]
R^2	99.4%	99.5%	99.4%	99.3%	99.4%
Adjusted R^2	99.2%	99.4%	99.3%	99.1%	99.3%
Predicted R^2	98.92%	99.09%	98.95%	98.78%	98.98%

**: All coefficients are significant at the 0.05 level. +: Values in bracket are the *VIF*

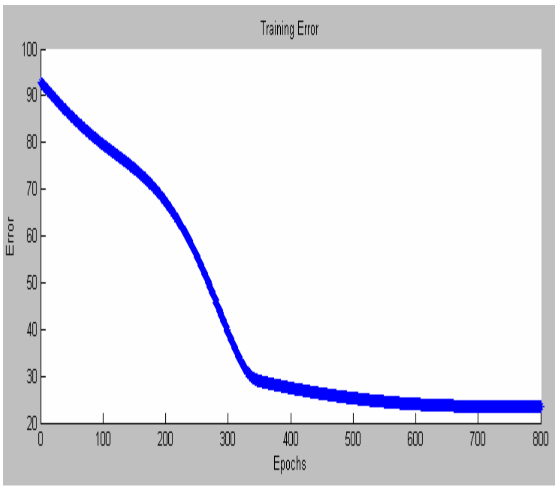


Figure 4: ANFIS training curve.

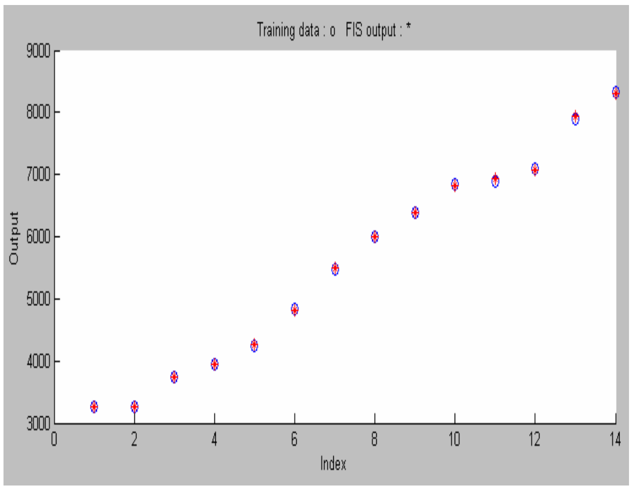


Figure 5: Actual and predicted electricity consumption values.

Different types of membership functions (MF) of the inputs and output were tested to train the ANFIS prediction system. A four Gaussian-type MF for capacity utilization (*CU*) input and two Gaussian-type MF for gross output (*G)* input, resulted in high accurate modeling results and minimum training and validation errors. The final (MF) were tuned and updated by the ANFIS model to achieve a good mapping of the input variables to the electricity consumption output. Figure 7 shows the final fuzzy inference system (FIS) used to predict the electrical energy consumption.

3.4. Models Comparison

The multivariate linear regression and ANFIS prediction models for Jordanian industrial electricity consumption were validated by feeding into the models the data points that were not used in model's building. The RASE values of the five models using the multivariate linear regression and neuro-fuzzy techniques are given in Table 4.

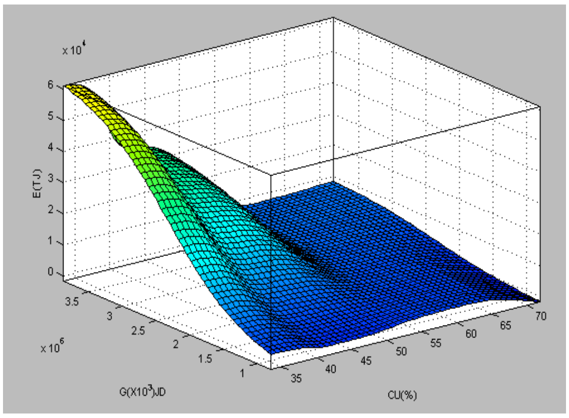


Figure 6: A model for predicting electricity consumption.

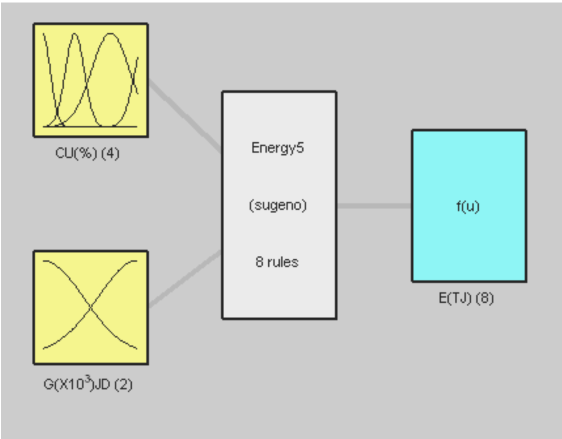


Figure 7: The final fuzzy inference system (FIS) for predicting electricity energy consumption.

Table 4: RASE and average error of multivariate linear regression and neuro-fuzzy models.

	Regression	Neuro-Fuzzy
	RASE (TJ)	RASE (TJ)
Model 1	132.15	94.75
Model 2	176.54	126.75
Model 3	168.19	175.00
Model 4	121.00	133.00
Model 5	143.80	69.75
Average	148.34	119.85

In General, as given in Table 4, the neuro-fuzzy technique achieved better results with a lower average value of RASE than the multivariate linear regression technique. Despite of this, the difference between prediction accuracy with neuro-fuzzy and regression is not significant and almost have the same performance. This is basically because the electrical energy data does not have highly nonlinear nature, where intelligent methods prove much better than other conventional techniques. Consequently, the performance of both techniques was shown to be almost the same.

4. Conclusions

Prediction of electricity consumption plays an important role in future energy related research and planning strategies. A multivariate linear regression method and an adaptive neuro-fuzzy inference system are used to model and predict the electrical energy consumption of the Jordanian industrial sector for the period 1985-2004. The significant factors affecting electricity consumption have been found to be industry's capacity utilization and gross output. The electricity energy consumption values predicted by multivariate linear regression and by ANFIS models are compared to the actual measured values in order to determine the error of both prediction techniques and validate the results. The following conclusions can be drawn from the above analysis:

1. A comparison between the multivariate linear regression and neuro-fuzzy models shows that the neuro-fuzzy model performs slightly better. However, difference is not significant and both models can be considered generally comparable.
2. ANFIS analysis shows that the capacity utilization, CU, input is more important in electricity prediction than the gross output, G. This is because the final MF of the CU are considerably different from the initial ones, while for the gross output, a very little tuning of initial MF parameters is occurred after ANFIS training. This shows the importance of ANFIS model in optimizing the electricity consumption process.
3. The present study shows that ANFIS is a technique that can be used efficiently to model and predict electricity energy consumption. It is believed that this approach can be applied to identify many other parameters in different fields.

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A Neuro-Fuzzy Reasoning System for Mobile Robot Navigation

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Abstract

An Autonomous Mobile Robot is an artificially intelligent vehicle capable of traveling in unknown and unstructured environments independently. Among the proposed approaches in the literature to handle the navigation problem of a mobile robot is the simple fuzzy reactive approach. This approach, however, occasionally suffers from two major problems, i.e., escaping from trap situations and the combinatorial explosion of the if-then rules in the inference engine. This paper presents a neuro-fuzzy reasoning approach for mobile robot navigation. The proposed approach has the advantage of greatly reducing the number of if-then rules by introducing weighting factors for the sensor inputs, thus inferring the reflexive conclusions from each input to the system rather than putting all the possible states of all the inputs to infer a single conclusion. Four simple neural networks are used to determine the weighting factors. Each neural network is responsible for determining the weighting factor for one sensor input. Simulation results are presented to demonstrate the merits of the proposed system.

Keywords: Neural networks; Fuzzy systems, neuro-fuzzy reasoning; Mobile robot navigation

1. Introduction

The ability of a mobile robot to navigate in unknown and unstructured environments by relying only on its sensory system is regarded as the key issue in an enormous number of research publications during the past 15 years [1]. In general sensor-based data acquired by the mobile robot presumably provides the necessary information to determine the appropriate control actions to the actuators so that the mobile robot can travel safely in cluttered environments with static and/or moving obstacles. In order to achieve its goal, the robot is usually required to determine in real-time a safe and smooth path from a starting location to an end location (target). Consequently, the main issues that need to be addressed in mobile robot navigation are reactive obstacle avoidance, and target acquisition [2]. It is well known that classical robot control methods that are based on precise models are only appropriate for industrial mobile robots that are designed to perform simple tasks and operate in structured and known environments. However, uncertainty is a major problem in mobile robot navigation process, and a robot is expected to deal and react robustly with present environment.

The evolvement of soft-computing paradigms have provided a powerful tool to deal with mobile robot navigation process, which exhibits incomplete and uncertain knowledge due to the inaccuracy and imprecision inherent from the sensory system [3,4]. Among all the soft-computing methods fuzzy logic based decision-making and neural networks have been found to be the most attractive techniques that can be utilized for this purpose. Fuzzy system is tolerant to noise and error in the information coming from the sensory system, and most importantly it is a factual reflection of the behavior of human expertise. In general, there are two approaches to the application of fuzzy logic in mobile robot navigation, namely, behavior-based approach [5-9] and classical fuzzy rule-based approach [1, 10-17]. However, the design of fuzzy logic rules is often reliant on heuristic experience and it lacks systematic methodology, therefore these rules might not be correct and consistent, do not possess a complete domain knowledge, and/or could have a proportion of redundant rules. Furthermore, these fuzzy logic rules can not be adjusted or tuned on real-time operation, and the off-line adjustment of their parameters is a time consuming process. Another problem could be raised when better precision is needed which is the huge expansion in the fuzzy rule-based system. Several approaches have been proposed in the recent literature to approach the above problems. A new grid-based map model called "memory grid" and a new behavior-based navigation method called "minimum risk method" was proposed by [18]. An integrated fuzzy logic and genetic algorithmic approach was presented by [19]. A hybrid controller that includes a support vector machine and a fuzzy logic controller was proposed by [20].

On the other hand, several successful reactive navigation approaches based on neural networks have been suggested in the literature [21-27]. In spite of the different suggested network topologies and learning methods,

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neural reactive navigators perceive their knowledge and skills from demonstrating actions. Therefore, they suffer from a very slow convergence, lack of generalization due to limited patterns to represent complicated environments, and finally information encapsulated within the network can not be interpreted into physical knowledge.

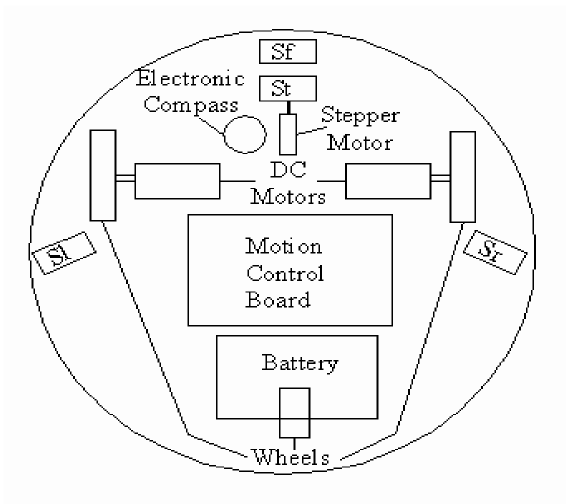
Recently the role of neural networks has been found to be very useful and effective when integrated with fuzzy control systems to produce what is called Neuro-fuzzy systems, and sometimes called fuzzy neural networks. Neuro-fuzzy systems provide an urgent synergy can be found between the two paradigms, specifically the capability to mimic human experts as in fuzzy logic, and learning from previous experience capability as in neural networks. In general, neuro-fuzzy systems can be classified into two categories, adaptive neuro-fuzzy inference system and hybrid neuro-fuzzy systems. The first category is the most widely used neuro-fuzzy systems, and they are designed to combine the learning capabilities of neural networks and reasoning properties of fuzzy logic. The main function of neural network is to learn about the fuzzy inference system behavior and uses this knowledge to adaptively modify its parameters [ANFIS, and others]. The adaptability of the fuzzy inference system can be achieved by either rule base modification and/or membership functions modifications. Rules can be generated, modified, and/or eliminated, while membership functions of the input variables can adjusted and tuned by scaling mechanism. The basic idea behind the use of the second category is to replace all or parts of the basic modules that builds a FIS. The only advantage that can be gained from such arrangements is the high processing speed, presuming that a hardware implementation of such neural networks exists.

In this paper a new approach to the design of a simple hybrid neuro-fuzzy navigation system is described. The suggested system has two apparent advantages. First, the if-then rule base is replaced by a set of simple neural networks. Second, inference is on the reflexive conclusions from each input to the system, rather than putting all the possible states of all the inputs to infer a single conclusion. Four parallel simple neural networks are utilized to generate weighting factors for the distance readings acquired by the robot's sensory system. These weighting factors represent the degree of collision avoidance by the robot from a certain side. These weighting factors are then treated as fuzzy values that are input to a defuzzifier to come up with a crisp value for the robot's steering angle and speed.

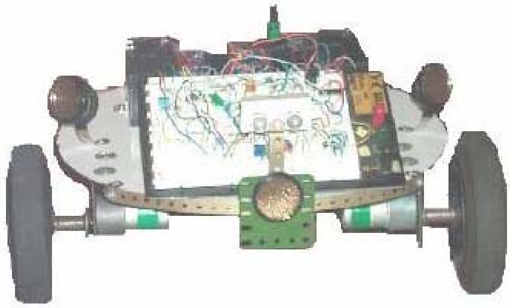
2. Experimental Prototype

SALIM, Simple Autonomous LIght weight Mobile robot, which was constructed at the authors' universities, has been used to conduct practical experiments. SALIM has a cylindrical shape with a radius of 30 cm, and travels at a maximum speed of 8m/min. The robot has two independent wheels, driven by geared PM DC motors, located at the ends of an axis near to one of the ends of the circular base, and one free caster at the other end of the base. Such arrangement provides a simple and effective differential-velocity steering control by varying the applied voltage to the motors. The motion control of the two PM DC motors is accomplished by a simple motion control board designed by the authors, which consists a full bridge chopper circuit, and PIC16f877 micro-controller. The advantage of using this micro-controller is that it accepts velocity commands from a remote computer and to control two DC motors independently.

Three groups of ultrasonic sensors are mounted at the front, and at the two ends of the central axis of the robot, where the right and the left sensors are directed at 45° from the central axis as shown in Figure 1. Target's orientation with respect to the center of the robot is obtained by an electronic compass. The actual angle between the robot frontal axis and the target can be found by simple manipulation to the robot's heading angle, which is updated instantaneously by the microcontroller, and that measured by the electronic compass. According to instantaneous value of this angle another ultrasonic sensor is utilized to detect the existence of any obstacle in the virtual target direction. This sensor is allowed to rotate, using a small stepper motor, in the range (-5° to 5°) with respect to the frontal axis of the robot. The reason in mounting the ultrasonic sensors in such arrangement will be mentioned in section (3). The error eliminating rapid ultrasonic firing (EERUF) method is used to minimize the error in distance measurements due to the noise that affect the ultrasonic sensors, and the crosstalk problem was eliminated by using alternating delays method.



(a)



(b)

Figure 1: Schematic of SALIM with sensor locations, a, b .

3. Navigation Process

Autonomous mobile robots at least need to achieve a simple goal of traveling safely and purposefully from one location to another in an environment that is unstructured and subjected to unpredictable changes. Like human beings, AMR should be self-reactive in the real world through decisions produced by a real-time navigation system. The reactions to the perceived surrounding can be inferred from either reflexive behavior or logical behavior. In general, the robot navigation problem is decomposed mainly into goal reaching and/or obstacle avoidance problems.

A typical trajectory of a mobile robot when navigating through an environment with unknown obstacles cannot be generated by the reactions to the sensed obstacle alone, but the direction of the target with respect to the robot should be considered. Depending on the location of obstacles with respect to the robot together with the robot's orientation with respect to the target, the navigation system should be capable of generating the right decisions to enable the robot to perform the necessary maneuvers to avoid the obstacles and not losing its sense of orientation towards the target. If the target reaching and obstacle avoidance behavior to be integrated together, the reactions of the robot can be categorized into four main types. If the robot is moving and it is not sensing any obstacles in its vicinity, or the obstacles are not blocking the target, then it can be said that robot is in the *free-heading mode* Figure 2(a). The second scenario is called *partial-front blocking mode*. In this situation the lines of attraction force due to the target will be disturbed and bend over the obstacle, therefore the turning reaction of the robot will be towards the varying direction of these lines, even if it moves away from the target, until it passes the obstacle and change its mode to the free-heading reaction mode, as shown in Figure 2(b).

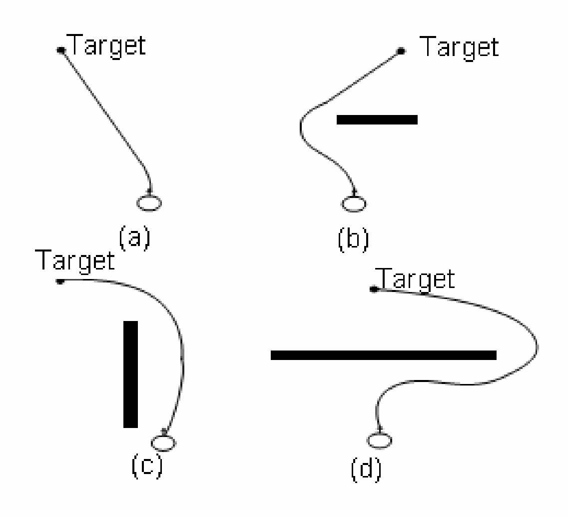


Figure 2: Typical Trajectory of a Mobile Robot While Avoiding Obstacles.

In the case of sensing an obstacle close to one of the robot sides that is blocking the straight-line path towards the target from the current position of the robot for some distance, as in the robot will be influenced by the side-blocking mode. In this case the lines of attraction force due to the target will be disturbed and bend over the obstacle as in the previous case except that it will follow the contour of the obstacle as shown in Figure 2(c). Therefore, the robot will move along this line while keeping a safe distance from the obstacle until it reaches the bent part of the line to change its mode to the free-heading mode. The final situation that might face the robot is when it is trapped due to the target attraction by a wide obstacle. The robot may make a significant turn to the left or to the right, and the robot here is under the total-front blocking mode. Once the robot turns to one of the two directions it will be then under the influence of side-blocking mode, and it will proceed in that direction while keeping a safe distance from the obstacle until it reaches the of obstacle’s end and again change its mode to the free-heading mode, as shown in Figure 2(d).

3.1. Navigation Methodology

When a mobile robot is traveling towards its final target it might face a variety of obstacles having different shapes and they may be randomly located in the path of the robot. Often in the literature, static obstacles can be classified into eight basic categories as shown in Figure 3. When fully conscious attention is paid to the environment, a navigation system could deal with large amounts of input information concerning near obstacles, and it should react instantaneously to provide a robust real-time reactions towards the foreseen surrounding. Therefore, its behavior should be how to avoid these obstacles, which simply can be answered move away from close obstacle by desired safety distance.

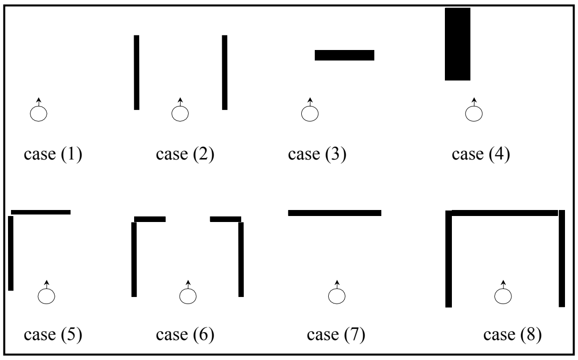


Figure 3: Classification of Obstacle Configurations.

Various algorithms have been proposed to attack the problem of generating collision free trajectories for a mobile robot by utilizing neuro-fuzzy systems. One of the methods used in designing a neuro-fuzzy navigation system, is based on training a neural network patterns of sensor readings corresponding to a variety of obstacles. Usually in such a methodology complete operator's experience is provided to the network and its training is supervised and performed off-line. Alternatively, partial operator's experience is provided to the network and its training is supervised and performed off-line at the first stage, and then navigator performance is enhanced by using on-line reinforcement learning. It should be noted that a robot may face during its course of navigation a variety of obstacles of different and complicated shapes that could be present in the surrounding, and they could be randomly located and oriented. Hence a huge number of patterns are required for the obstacle recognition methodologies, or a very long time will be required for unsupervised learning methodologies. ANFIS

From the above discussion, it is believed that it is better to consider the navigation process to be based on a very simple human experience to generate the reaction of the mobile robot towards the surrounding through neuro-fuzzy reasoning. Such system is based on two facts, first humans cannot get used to all the possible arrangements of obstacles and second cannot build a huge fuzzy model that contains all the possibilities of the 'If...Then...' rules. Instead, they give weighting factors to which direction they are going (left, ahead, right) and what their speed should be, and this possibly can be made based on information from the different senses. The neuro-fuzzy reasoning system suggested in this work, see figure 5, consists of a neural network/s responsible for generating independent certainty weighting factors for the three basic directions (left, ahead, and right) corresponding to instantaneous sensory information. These decisions are then combined, with the same level of simplicity by a diffuzifier, to obtain a final conclusion. The main objective of the proposed method is to reduce the size and time required by a fuzzy inference system by combining the learning capability in neural networks and reasoning capability in fuzzy inference systems, without affecting the efficiency and performance of the navigation system when compared to other classical implementations of reactive fuzzy and neuro-fuzzy navigators.

3.2. Learning Methodology and System Structure

For the first glance, the neuro-fuzzy system architecture was intended to have a multi-layer standard feed-forward neural network. The inputs to the NN are sonar data, representing the distribution of obstacles in foreseen surrounding, and the virtual angle between the robot and the target, while the output that should be produced from the network are certainty weighting factors for the three basic directions and a weighting factor for the target orientation. The training set was supposed to be obtained during driving sessions of the robot by a human operator in different situations, while sensed distances and the four weighting factors are to be stored during these sessions. Two factors resulted in total failure of such method. The first was the difficulties that faced all the operators to give four answers corresponding for the certainty weighting factors. The second factor is related to that a good quality of learning requires huge, significant and complete training examples. In these training examples human operators should guarantee the consistency of their reactions without any contradictions.

Under such difficulties an alternative learning approach was considered. The approach is based on a divide-and-concur strategy; where instead of having single multi-input neural network four three-layer neural networks were used. Each network is designed to receive only the distance measured by the corresponding group of ultrasonic sensors from the robot to any possible obstacle that may detected in that direction and generates a weighting factor that represents the degree of certainty to avoid the collision with the obstacles at that side. To generate the required data to train the neural networks a group of operators were required to answer a questionnaire asking them to represent their judgment to the measured distance and the degree of certainty weighting factor in a fuzzy format. Each measured distance was represented by five fuzzy values, Very Far (VF), Far (F), Medium (M), Close (C) and Very Close (VC), while the weighting factors were also represented by five fuzzy values, Very High (VH), High (H), Medium (M), Low (L) and very Low (VL). By averaging all the answers, the universe of discourse of both variables and their representation in terms of fuzzy sets were defined as shown in Figure 4. Consequently, a single input single output fuzzy system designed to provide a mapping function between the measured sonar distance and certainty weighting factor, from which a training data for the network training were obtained.

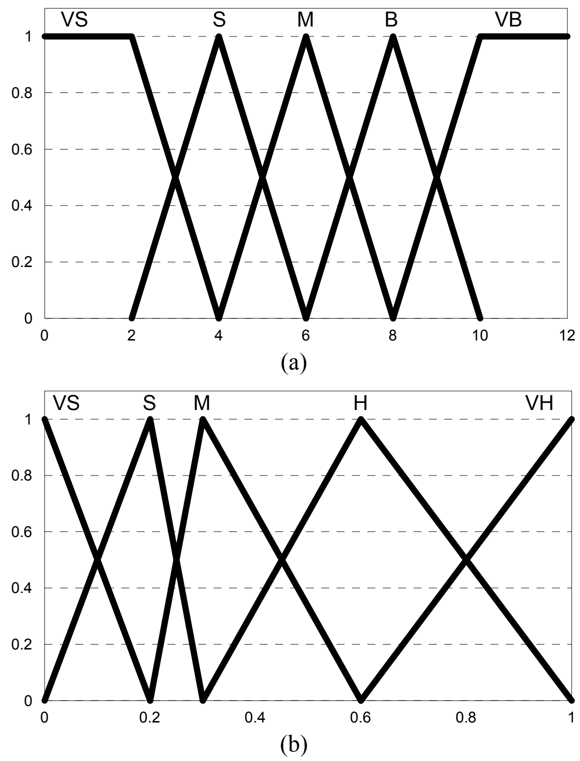


Figure 4: Fuzzy sets representations of (a) sonar measured distance, (b) weighting factor.

The structure of the proposed system is shown in Figure 5. Four input variables are required to provide the necessary information for the navigation system to safely drive the mobile robot to reach the desired target. These inputs are: distances d_f, d_r, and d_l, measured by three ultrasonic sensors. These distances are the distances between the robot and any possible obstacle with respect to the local front, right, and left directions of the robot, respectively. The forth input, d_{vt}, is the distance directed in a global virtual direction between the robot and the target. The outputs of the system are the steering angle θ and the speed of the robot ν. The idea of using a virtual target orientation instead of the real orientation comes from a realistic representation to the behavior of expert driver, where it is impossible for a driver to abandon his attention to the frontal sight when leaving a one-sided blocked target behind him and concentrates on the real target orientation. Under this situation the driver put some concentration towards a virtual orientation at the same side of the target, which should not exceed a certain limit in the range of the frontal sight.

Each distance variable from the corresponding sensor is then input to a simple neural network to generate a weighting factor that represents the degree of collision avoidance of the robot from the side of the corresponding sensor. The output weighting factors of each network were values between 0 and 1, with 0 value stating that the robot is very close to an obstacle and a value of 1 stating that the robot is very far from the obstacle. The structure of the four neural networks is identical and is depicted in Figure 6. Each network consists of a single input node, a single output node, and a single hidden layer with ten nodes. Back propagation has been used to train the networks. The middle block in the system is a simple defuzzifier that receives the four weighting factors coming from the previous neural network subsystems, and treats these factors as the degree of fulfillment for the corresponding fuzzy values of the steering angle of the robot. The Center of Area method is used in this block to obtain the final crisp value for the steering angle of the robot. The membership functions for the fuzzy values of the output variable θ are shown in Figure 7. Only three of the fuzzy values are shown in Figure 7, i.e., the turning angle to the left, center, and right, respectively. The fuzzy set that represents the steering angle towards the target orientation is similar except that it is designed to be floating with its center moving in the range [-30°, 30°].

Once the final value for the steering angle θ is obtained, the robot's speed can be computed by a two-input neural network as shown in Figure 8. The inputs to the neural network in Figure 8 are the steering angle θobtained from the previous stage and the distance d_t that represents the distance between the robot and the obstacles with respect to a virtual target. The input distance d_t is used to slow down the robot as it approaches the target. The training sets for the neural network in Figure 8 were obtained by simulating the robot's motions and estimating the required speeds of the robot for different values of d_t and θ.

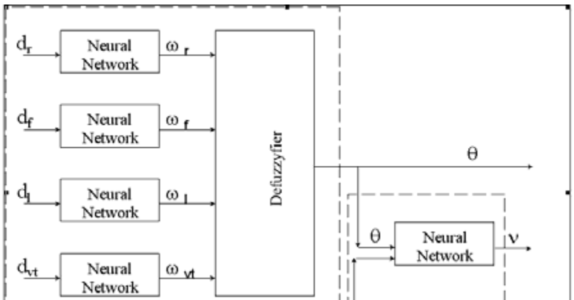


Figure 5: Structure of the proposed system.

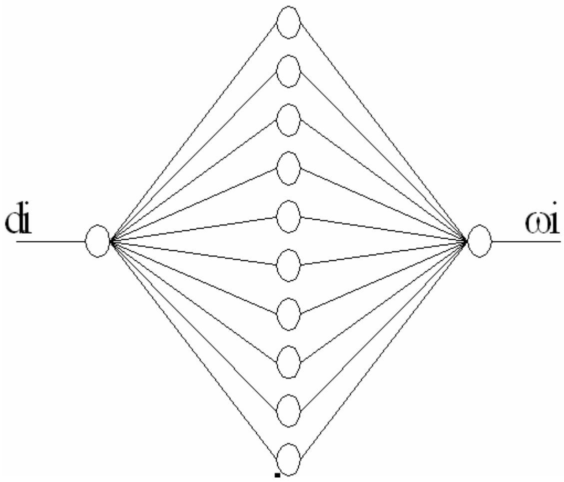


Figure 6: Neural network structure for weighting factors.

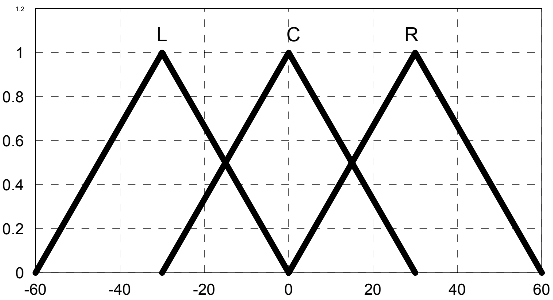


Figure 7: Fuzzy set definition for the output variable θ.

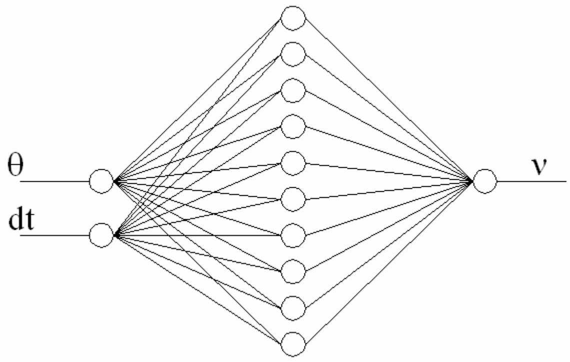


Figure 8: Neural network structure for speed calculation.

4. Simulation Results

In order to confirm the efficiency of the proposed method, a simulation program with a graphical user interface has been developed on a Pentium III personal computer using Visual Basic 6. The robot is depicted in the simulation as a circle to resemble a prototype mobile robot that the authors have designed and constructed for experimental purposes. It is noted here, that errors due to wheel slippage and other motion errors were not considered in the simulation. Distance measurements were acquired by four ultrasonic sensors mounted on the robot. Each sensor was modeled by a number of rays within a sector region of a wide beam-angle. The distance measured by each sensor is considered to be equal to the minimum distance obtained within the sector of each sensor while taking into consideration the minimum reliable distance that can be measured by actual ultrasonic sensors. Six different simulation cases are presented in this section to analyze the reaction behaviors of a mobile robot in avoiding a variety of unknown static obstacles placed randomly in a portion of an unknown environment. The aim here is to study the performance of the proposed approach under the most possible situations. In all these cases the robot is assumed to be initially moving with full

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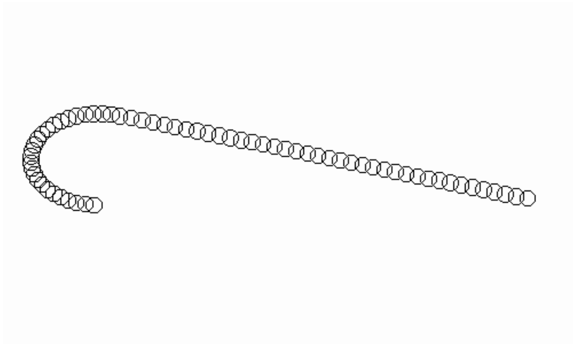

Figure 10: Case 1: Robot path with no obstacles.

speed and its relative steering angle is assumed to be zero. The analysis of the reaction behaviors of the robot is based on observing the instantaneous variation of the four weighting factors and their influence on both the steering angle and speed.

In the first case, Figure 10, the robot is initially oriented in an opposite direction to the target. In this case no obstacle is sensed by any of the four sensors. Hence, the values of the four weighting factors are all equal to 1 (see Figure 11). Consequently, the robot will be in the *free-heading mode*. The immediate reaction of the robot will be biased to turn towards the side at which the target sensor is located at that instant since the *Turn to Left* and *Turn to Right* sets are equally scaled. The variation of the steering angle and its influence on speed, Figure 12, depends on the location of the center of the *Turn to Target* set, which is allowed to move in the range [-30, 30] depending on which side the target is at that instant.

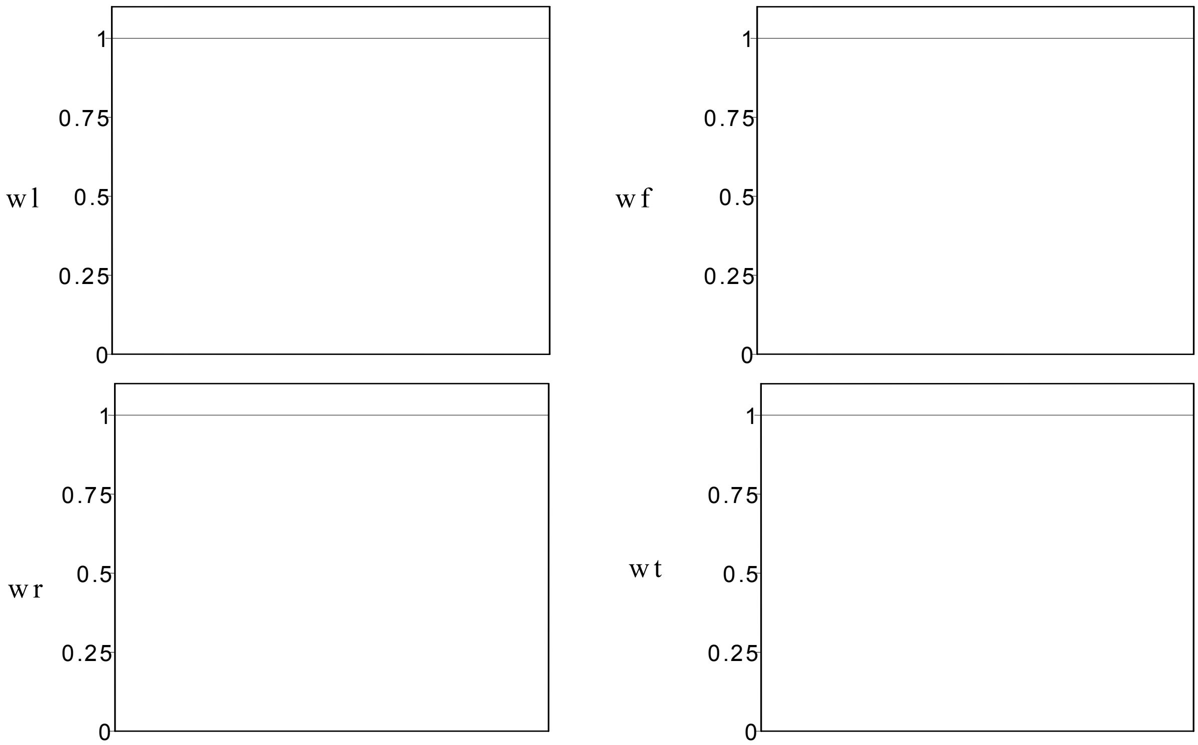

Figure 11: Behavior of weighting factors for case 1.

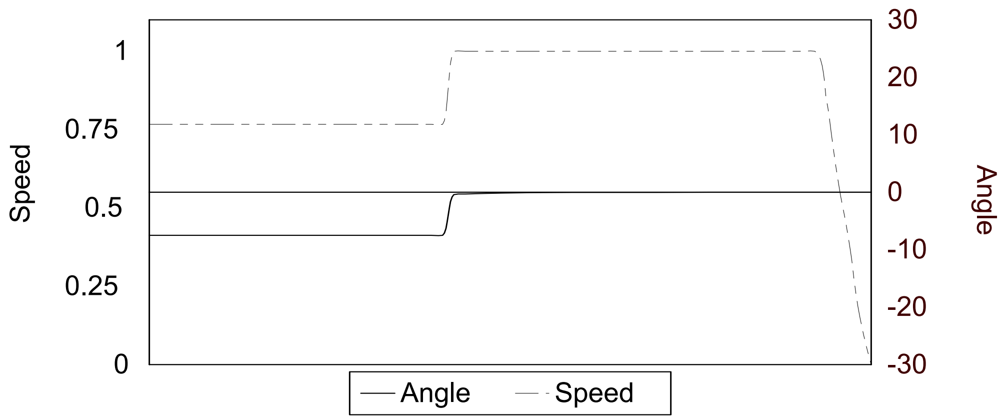

Figure 12: Behavior of steering angle and speed for case 1.

In the second case, Figure 13, the robot is passing through an empty L-shaped tunnel where the only present obstacles are the parallel bounding walls of the tunnel. The response of the robot towards the walls is influenced by the instantaneous variation of the weighting factors as shown in Figure 14. At the first instant the level of cautions towards the obstacles at both sides are equal, while the weighting factors for the front and target sensors indicate that there are no obstacles in either direction, thus the robot will move towards the target. As the robot proceeds in moving towards the target the steering angle will be gradually reduced because of the continuing increase in the difference between the right and left weighting factors and the fall of both front and target weighting factors (see Figure 15). Once the robot becomes close to the right wall the left weighting factor will rebalance the congregated right and target weighting factors. Thus, the robot will slightly turn to the left until it aligns itself to move later in parallel with the right wall. When reaching the end of the tunnel, the target weighting factor will rapidly increase to 1. Hence, the robot will noticeably reduce its speed for a short while until it is completely turned in the direction of the target.

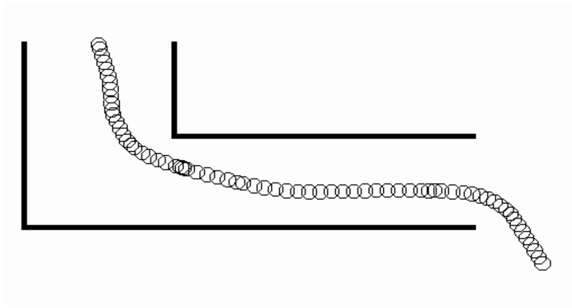

Figure 13: Case 2: Robot path through L-shaped tunnel.

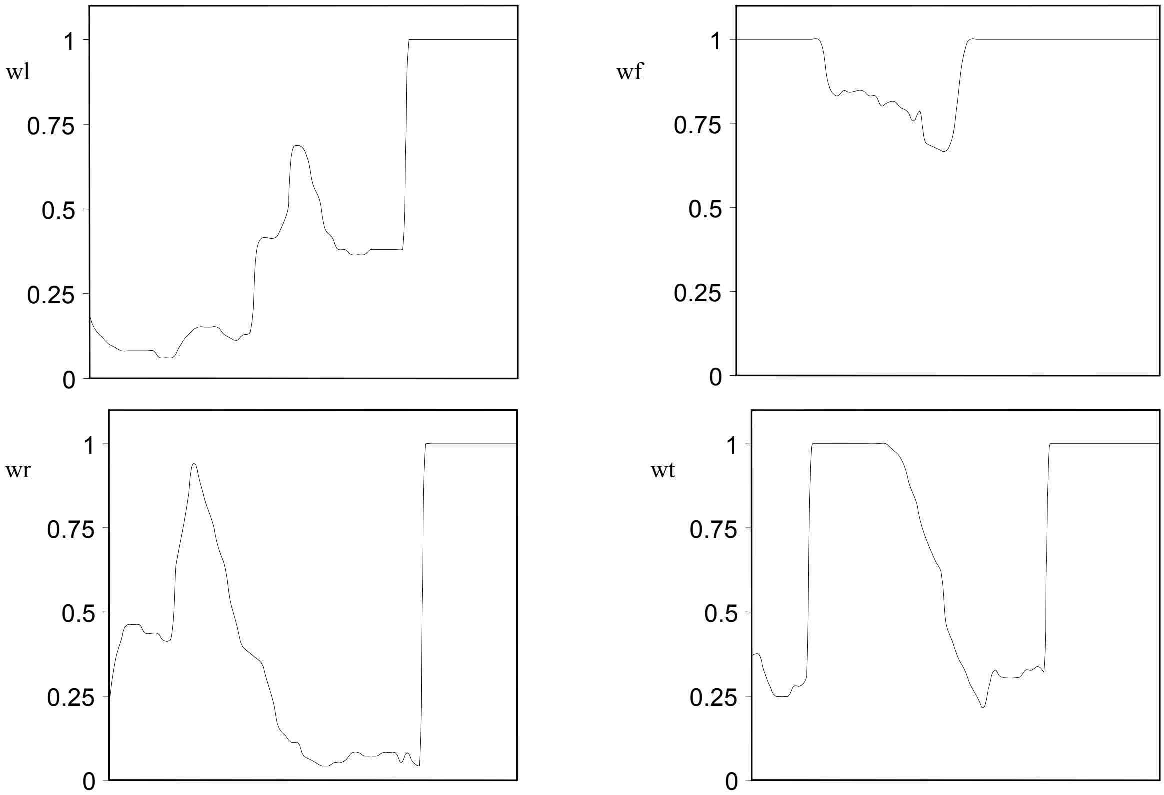

Figure 14: Behavior of weighting factors for case 2.

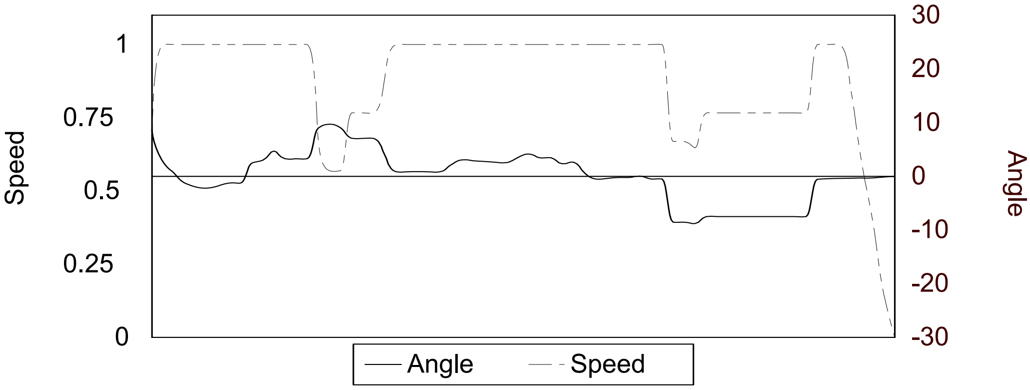

Figure 15: Behavior of steering angle and speed for case 2.

The third case, Figure 16, the robot is heading towards the target at full speed when a square obstacle blocks its path. The obstacle totally blocks the robot from the right side and slightly extended above the line that connects the location of the robot and the target. As can be seen in Figure 17 the first apprehension is from both the front and target sensors through the decreasing values of their corresponding weighting factors. The right sensor detects the presence of the obstacle, and the robot immediately reacts by turning gradually to the left while reducing its speed due to the dominance of the left weighting factor (see Figure18). Once the robot passes the obstacle both the front and the target weighting factors increase sharply. The right weighting factor follows and rises sharply to indicate the absence of any obstacle in all directions. Reacting immediately to this situation, the robot reduces its speed and turns to the right side to align itself again with the target direction (Figure 15).

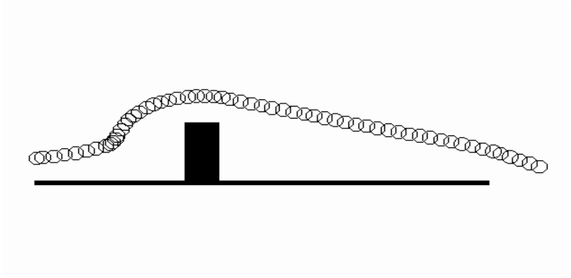

Figure 16: Case 3: Robot path blocked by a square obstacle.

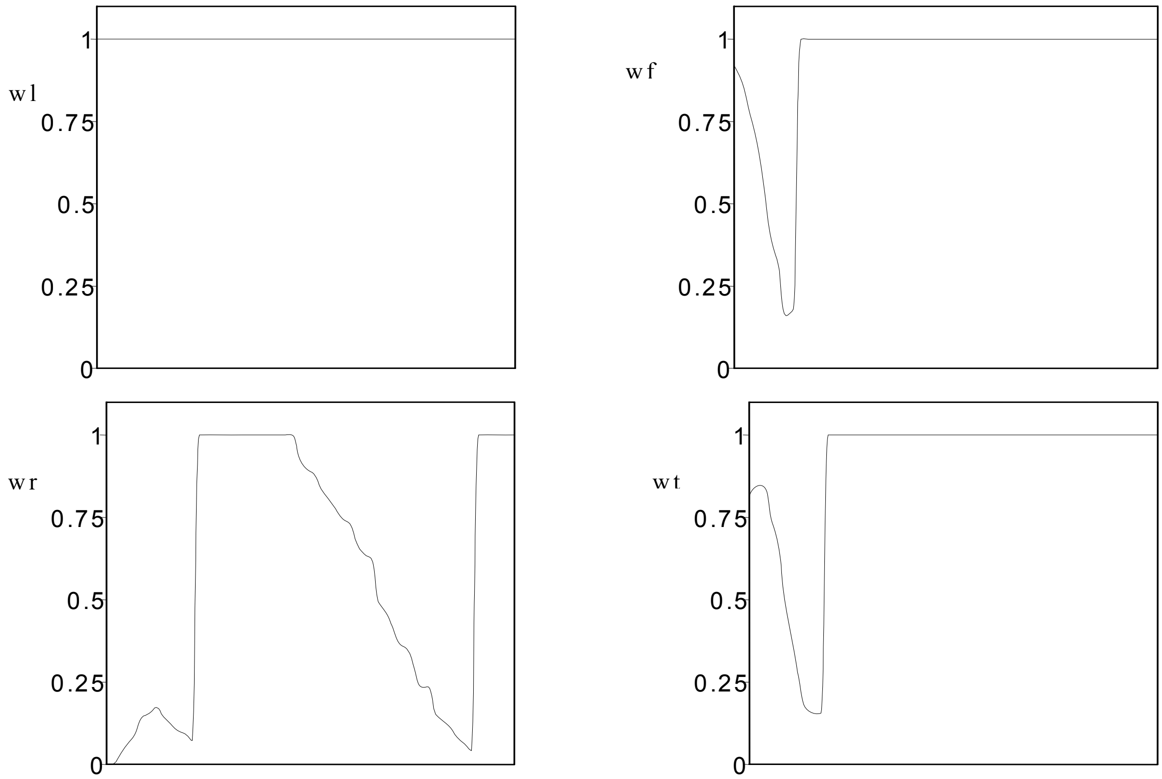

Figure 17: Behavior of weighting factors for case 3.

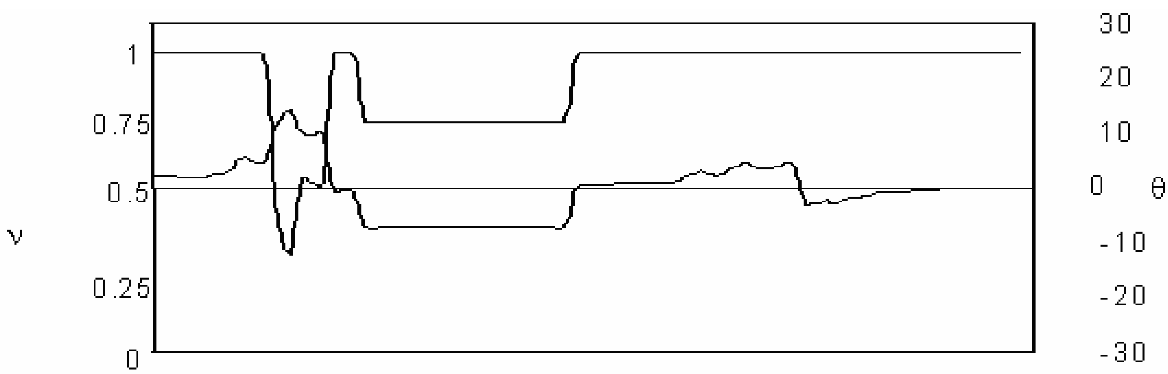

Figure 18: Behavior of steering angle and speed for case 3.

The next case presented is depicted in Figure 19. The case describes the situation when the robot is moving in a room while the target is in another room. The behavior of the robot in the beginning is similar to that in the previous case until the robot is faced with the corner walls. At this time only the right weighting factor is active will all other factors are zero. Consequently, the robot turns to the right. Once the robot turns to the right its path becomes blocked from both the left and front again. Hence, it keeps on turning to the right until the front weighting factor is active. The robot keeps on moving in the same direction until the right weighting factor is 1 at which time the robot turns back towards the target.

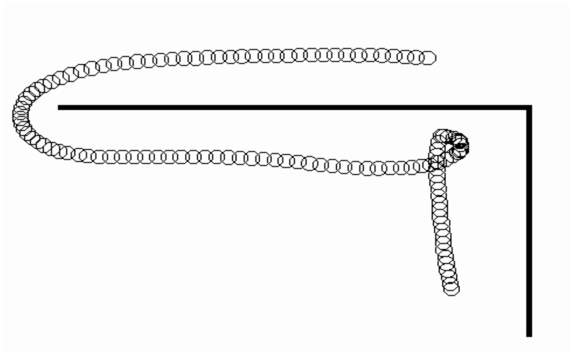

Figure 19: Case 4: Robot path when target is in another room.

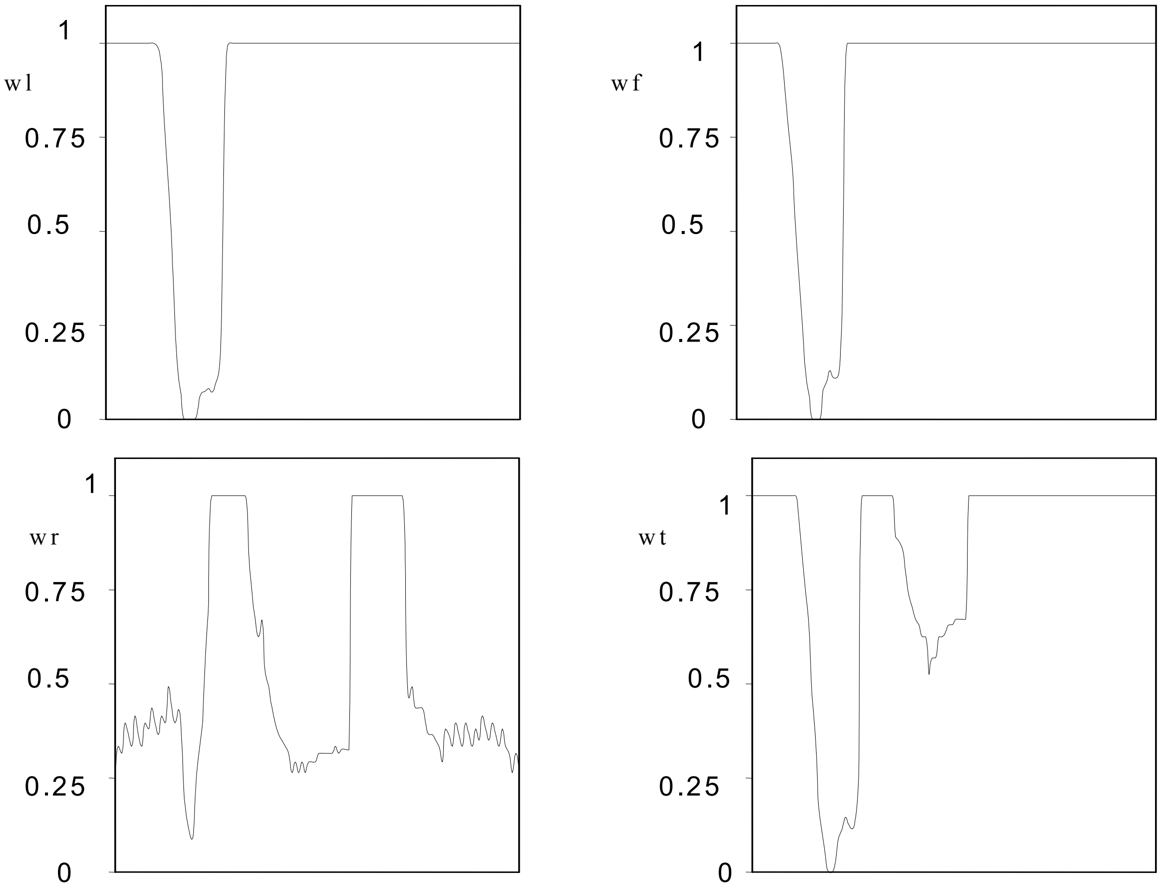

Figure 20: Behavior of weighting factors for case 4.

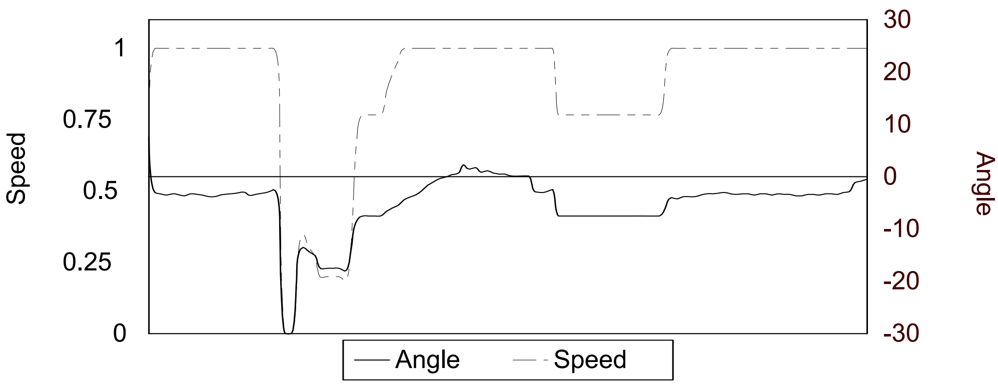

Figure 21: Variations in steering angle and speed for case 4.

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The case depicted in Figure 22 tests the reaction of the robot when trapped by a wide obstacle while the target lies along the robot heading direction. In this situation the effects of both the right and the left weighting factors will cancel each other, and the robot will continue moving along its initial heading direction. As the robot gets very close to the obstacle all the weighting factors fall to zero (see Figure 23). In this situation, an assisting rule within the defuzzifier is activated and the robot will turn 90° to the left. Immediately after activating the rule, the left weighting factor rises to 1, while the other factors remain zero for a short while. This results in getting the robot to turn to the left until it is away from the obstacle by a safe distance. The effect of the target weighting factor rebalances the turn to the left behavior. Once the critical situation is overcome, the robot behaves in a similar manner to that of case 3.

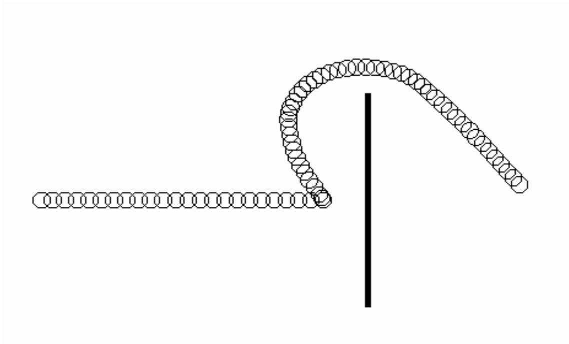

Figure 22: Case 5: Robot path totally blocked by a wide obstacle.

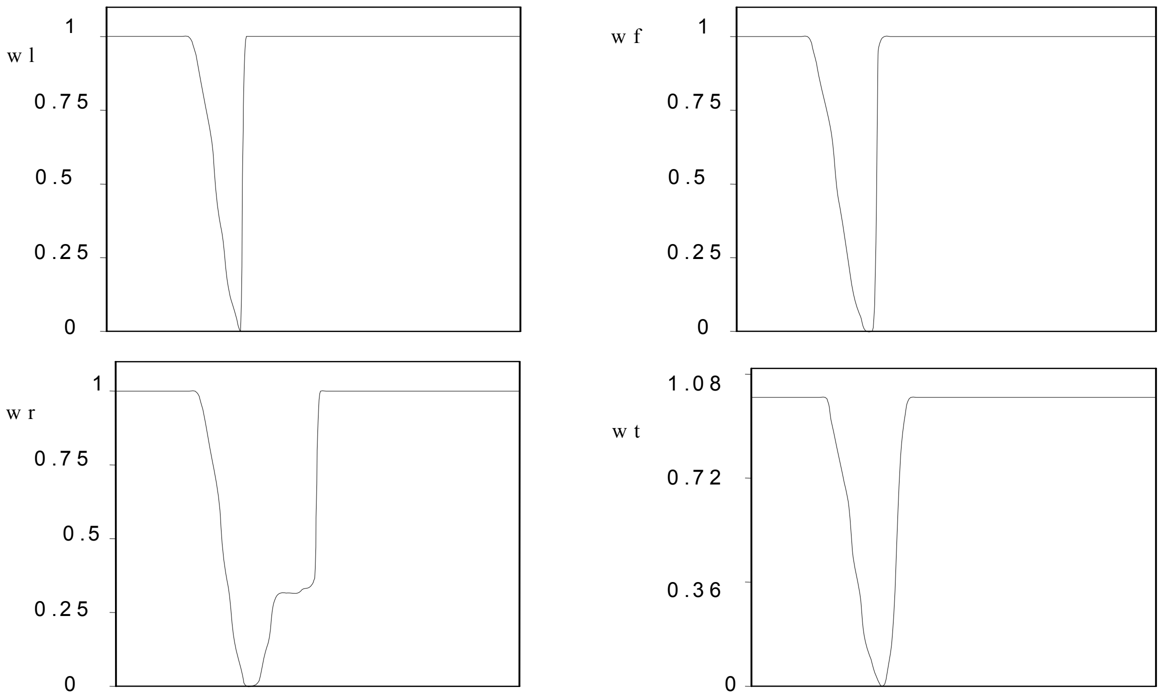

Figure 23: Variations of weighting factors for case 5.

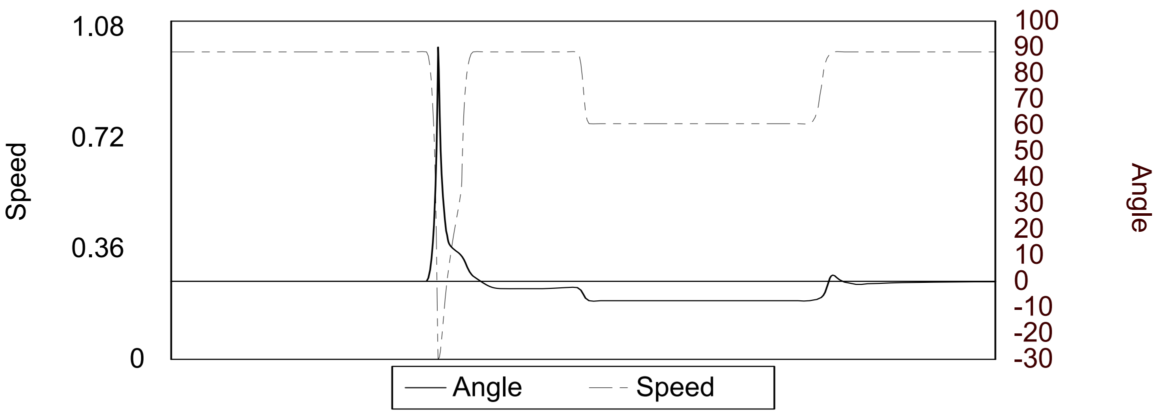

Figure 24: Variations in steering angle and speed for case 5.

The final case, Figure 25, presents the situation where the robot is trapped by a dead-end. The behavior of the robot in this case is very much similar to that of the previous case. When faced by the dead-end, the robot starts turning left under the effect of the assisting rule. Once the robot turns left, the other side of the concave obstacle will block its path. Hence the robot keeps on turning left until it is totally away from the target. Furthermore, due to the narrowness of the tunnel, the robot will keep on moving away from target until it gets close to the opening. At this time the target attraction behavior becomes dominant and the robot turns and moves until it reaches the target.

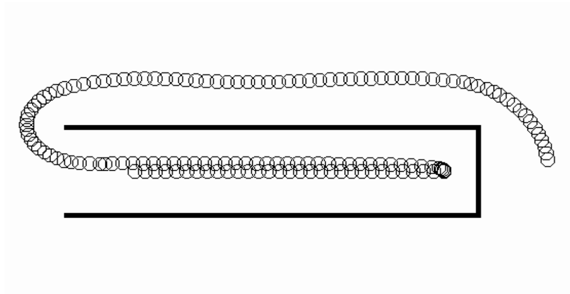

Figure 25: Case 6: Robot path when trapped by a dead-end.

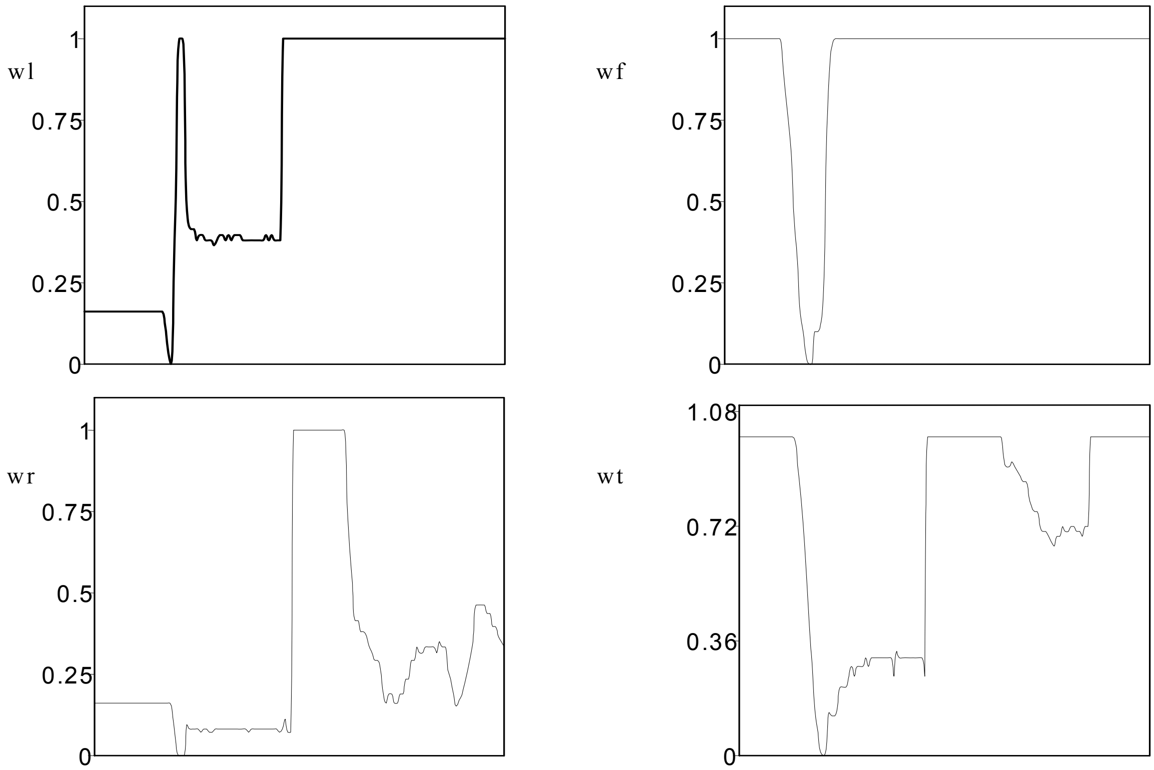

Figure 26: Behavior of weighting factors for case 6.

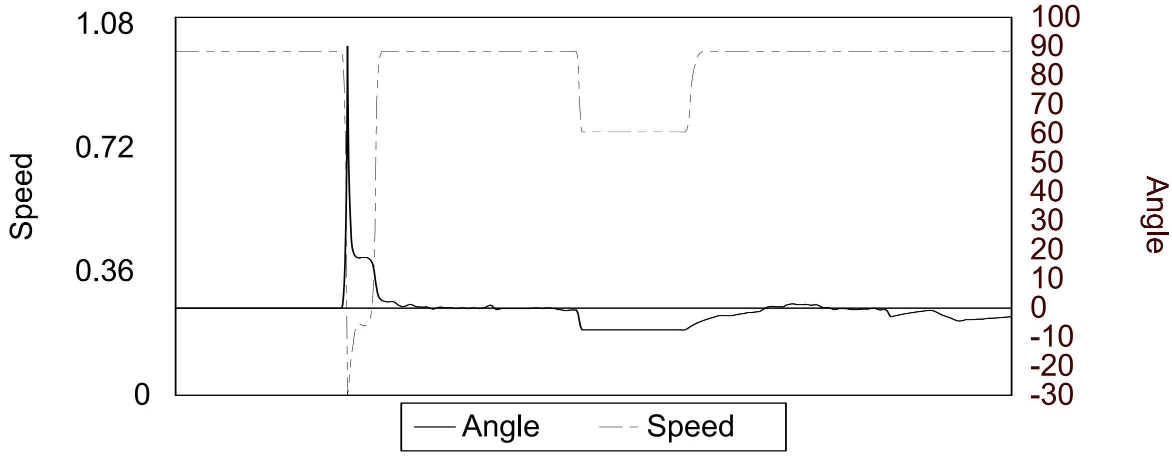

Figure 27: Behavior of steering angle and speed for case 6.

5. Concluding Remarks

A neuro-fuzzy reasoning scheme for mobile robot navigation has been presented in this work. The approach is based on decomposing a multidimensional fuzzy system into a set of simple parallel neural networks. This method relies upon finding quantifiable means to represent the expert's experience, and determines a mapping from current state of a system to the fuzzy measures with which the expert's knowledge is quantified. The concept of weighting factors for the sensor inputs expressing the reflexive conclusions of each input rather than having to go through a huge list of rules to infer a single conclusion is introduced here for the first time. Therefore, the method has the advantage of replacing the huge number of "If-Then" rules by simple parallel neural networks. The approach was tested in a number of simulated case problems to demonstrate its effectiveness, and it was found that the results compromise with reasonable satisfaction the obstacle avoidance and target reaching requirements. In addition to that, the proposed controller showed the capability of a mobile robot to escape from simple traps.

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