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Decision Support Systems in Arthritis Diagnosis

G. Rumbe[1], L. Wang[1] and H. You[1]

[1]Department of Systems Science and Industrial Engineering, State University of New York at Binghamton, New York 13902, USA.

ABSTRACT

Arthritis has been identified as a deadly disease which leads to the suffering of patients from limited mobility and visual and mental impairments. Patient's safety has been a key issue within the healthcare delivery systems and more preventive efforts are being employed in curbing the increase of Medical Diagnostic Errors (MDE). MDE provides an enormous challenge to care personnel since they may occur due to various reasons. This necessitates the need to provide a timely and accurate diagnosis to reduce the chances of patients' complications. Furthermore, it enables the availability of adequate resources to assist in meeting the patients demand. The use of Medical Diagnostic Decision Support (MDDS) system provides an effective method which proposes recommendations from the input and can be used as a gateway by the physicians prior to extensive laboratory testing. The MDDS system proposed evaluates variety of inputs (arthritis factors) by the determined heuristic rules and criteria's implemented within the PowerBuilder software.

Keywords: Decision Support Systems, Medical Diagnostic Errors

1. INTRODUCTION

A Decision Support System (DSS) refers to computer program that aids in providing recommendations to various complex problems. There has been extensive utilization of DSS in various domains. The use of DSS spans from manufacturing, business and even healthcare systems [11]. In the healthcare systems, there has been an increase in the number of death due to MDE.

According to statistics, 180,000 deaths occur due to MDE and these errors are ranked among the 5^{th} leading cause of death in the US [4].

Patients' diagnosis has been a challenge within the healthcare systems. Effective and efficient diagnosis systems require an extensive knowledge of patients and their diseases levels [7]. Such knowledge may be difficult to acquire due to the dynamic changes of the pathogens forms and this may induce MDE occurrence. On the other hand, known diseases and other health related factors can be modeled and incorporated in the MDDS system to aid in decision making. In addition, it has been approximated that humans utilizes at most 2 million pieces of information in the decision making process and in the field of biomedical, it is cited as increasing twice fold in a span of 20 years [2]. This has left many physicians struggling with an overload of information each time they have to provide diagnosis to the patients [2]. The DSS are not only used for diagnosis within the healthcare systems but also support other related functions. Table 1 shows some examples of the DSS functions.

Table 1: Functions of Decisions Support Systems [2]

Function	**Example of routine use**
Alert	Clinical laboratory systems highlighting abnormal values
Diagnosis	Producing a differential diagnosis for pediatric rheumatic disease
Reminder	Reminding the clinicians to schedule an immunization visit
Suggestion	Suggesting adjustments to adjust medical ventilation
Interpretation	Pediatric electrocardiogram interpretation
Prediction	Predicting mortality from a Pediatric Index Mortality (PIM) score
Critique	Reviewing total parenteral nutrition prescriptions
Assistance	Assisting selections of optimal antibiotic choices in neonatal infections

Initial MDDS systems were grouped as, clinical algorithms, mathematical models, expert systems and pattern recognitions systems [7]. They employed algorithms involved balancing the diagnosis model complexity and ability to infer to the stored database knowledge to provide accurate and timely responses to the users. The logical systems have been incorporated in the MDDS systems to provide accurate measures and determine extensions on the diagnostic tests which have intersecting subsets depending on the characteristics of two diseases [7]. The MDDS systems evolution from 1980-1990's have been enhanced due to the development of hardware and Graphical User Interface (GUI). The MDDS systems can be classified into three categories, general, intermediate and focused MDDS systems. A General MDDS system has a wider application as compared to the rest of the group.

Arthritis has been identified as being among the worst seven chronic conditions which affects a large population in the US. Other conditions include diabetes, hearing impairment etc. Some of Arthritis malignant factors include limited mobility, and other structural, sensory and communication abnormalities. These conditions are degenerative in nature and without accurate diagnosis during the initial phases may become permanent for the rest of the patient's life [12]. This necessitates the need to provide accurate and timely measures so as to enhance the patient's life.

1.1 Research Objectives

The main goal of this research is to examine the preliminary application of DSS performance in determining accurately the patients suffering from arthritis illness. This will enable the physicians to provide a suitable intervention, and further optimize the medical resources in terms of physician time, facilities etc. In addition, the research explores the impacts of the use of MDDS system within the healthcare domain.

1.2 Research Layout

The research is organized as follows: Section 1 introduces the Decision Support System; presents some applications of DSS in different domains and its importance/benefits. Section 2 provides a brief literature review on the MDDS systems with the healthcare domain. It also summarizes the benefits obtained by its use. Section 3 describes the methodology used and the different input parameters considered. A brief description on the use of Prolog and PowerBuilder and the reason for their selection is discussed. Section 4 provides details on the analysis and also presents discussions on some of the heuristics rules employed. Section 5 summarizes the research analysis and proposes other possible extensions.

1.3 Motivation

The motivation for this research was driven by increase in the number of erratic diagnosis which has been determined to be costly to both the patients and health systems. In addition, it forces physicians to engage resources and other utilities which would have been rather committed to aid in medical interventions and as a result increase the patients' throughput.

2. LITERATURE REVIEW

Various DSS have been built to assist in disease classification such as chest pains, treatment of infertility and immunization interventions. By the use of computerized systems results can be generated. Accurate classification of different related disease is vital in enhancing the patient's recovery and reducing any unprecedented errors [1]. The limitations of the classification criteria is that they contain only the major characteristics of the disease and therefore needs not to be construed fully as the truth but can be used in as an aid in decision making process [1]. Majority of the Arthritis diseases researched have multiple factors and this provides difficulty for the medical staff to determine the accurate diagnosis. In addition, patients are therefore subjected to strenuous medical testing which increases their wait times in the clinics.

In order to overcome this problem, initially classification trees were designed to perform identification checks in determining patient ailments. The classification trees were developed based on patient's history and past medical examinations results. Figure 1 demonstrates an example of classification [1].

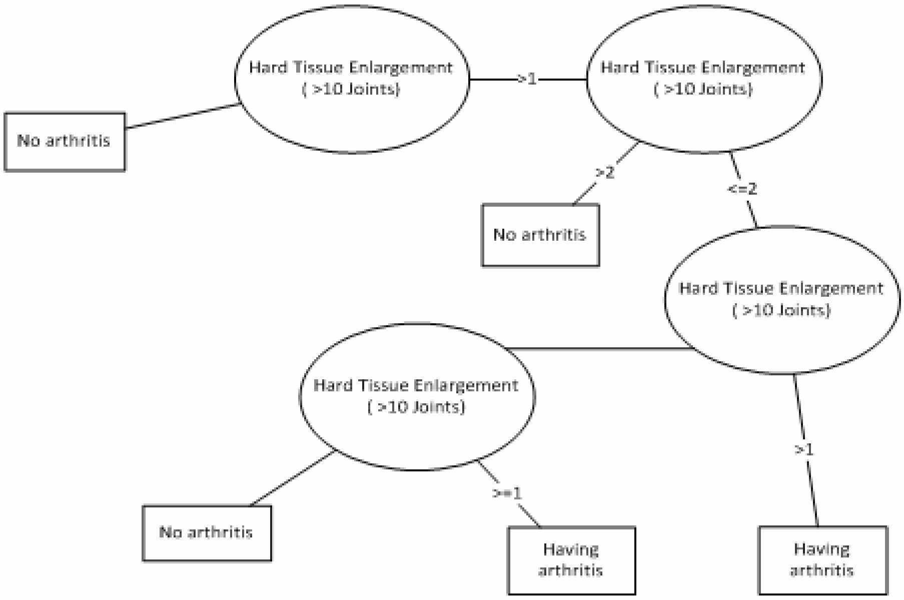

Figure 1: An Example of Arthritis Classification Tree [1]

Healthcare systems are gradually embracing the use DSS to improve efficiencies and the quality of services offered. The DSS are designed to enhance the clinical decision making process. The format employed has the systems match each patient's characteristics to the stored knowledge systems, and the heuristics rules provide certain recommendations for actions. Such DSS can aid not only the physician but also the rest of the medical staff [3]. Some of the DSS application studied in the previous literatures includes, enhancing patients outcomes and safety [9], reducing the patient's medication errors [6].

The focus of this research was to explore the most optimal treatment to reduce physician diagnosis time and enhance the physician-patient relationship within the healthcare delivery systems. Arthritis was selected since it has been described as one of the harmful diseases with the US. According to statistics it is estimated that 21 million people in the US are affected by the disease. This disease causes patients immobility through inflammation of one's joints. It has been identified that there exist more that 100 forms of illness related to arthritis thus requiring the need of DSS to aid in recommending the significant factors [5]. Some forms of arthritis include Rheumatoid, Psoriatic, Septic, Gouty, and Osteoarthritis among others.

Other methods which have been utilized to provide accurate diagnosis includes the use of Expert Systems which relies on rule based systems and inferences, artificial intelligence Neural Network which is adaptive in nature among other systems [10]. Use of a setup database in Artificial Intelligence (AI) was utilized as reservoir where all related patients information was stored and the systems could infer to this basing on the patients disease and generated all possible diseases. These diseases were ranked by an approximation and the belief values in each disease [8].

Furthermore, fuzzy set theory has also been applied in the development of efficient MDDS. Some of the concepts considered include aspects of incompleteness, inaccuracies and uncertainties which have been identified in medical records. Examples of diseases applied are rheumatologic disorders and pancreatic diseases. The schemas employed by fuzzy set theory encompasses the degree of truth values which a patient shows related to the kind of disease and is measured from a scale of '1' and '0'. The representation of '1' indicates the complete existence of a disease while '0' shows the non-existence of a disease [7]. Arthritis can be determined by identifying the different symptoms. Although there are some similarities in the symptoms, there exist differences in particular symptoms which distinctly distinguish one from the other. Some of the symptoms are redness, swelling and stiffness, feeling of fatigue, deformity of joints, persistent joint pains etc [5].

2.1 Effects of Erratic Diagnosis

Providing accurate diagnosis needs to be enforced among physicians and the supporting staff since there are involved repercussions which may be much more costly. Some of the effects are:

- Erratic diagnosis may lead to financial constraints if the patients are not diagnosed or informed accurately, whether they are ill or about his\her ailments and later determines that they are after being subjected to a series of unnecessary laboratory tests.
- It may also induce subjection of the physicians to the legal inquest which is taxing and time consuming and there may be penalties involved and careers at stake.
- In addition, it may also lead to death and emotional distress to the patients, patient's family and negatively impacts the hospital reputation.

2.2 Advantages and Disadvantages of Decision Support System

The DSS despite not extensively used in all healthcare systems should be noted as aiding in improving the services offered. On the other hand, it should be noted that human intervention may perhaps always be required. Some of the benefits achieved by the DSS include

- Enhanced efficiency and reduction in cost. Service delivery is much faster and the patient is treated for the accurate ailment therefore it minimizes irregular allocation of resources in terms of testing [3].
- Improves the physician decision making and thus enhances his\her performance. The physicians' are able to make quick decisions with the assistance of DSS and thus focuses on the necessary medical interventions to enhance the patients' lives.
- Other expected benefits may include an increase in the number of patients' throughput, reduced wait times for patients, and improved resource allocation.

There are numerous challenges facing the development of health systems. Healthcare within the US is gradually changing to utilization computerized medical records and medical information databases. These changes have been induced due to the Information Technology (IT) advancement. Some of the drawbacks facing the use of DSS

- Due to the discovery, innovations of new research and improvement in diagnosis, new interventions are always proposed which would require update and future integration with the current systems.
- This will also lead to increase in cost in purchasing any new systems, maintenance cost, and update of the DSS system to be utilized within a healthcare system.
- In addition, for each disease it may require standalone decision support systems which may prove to be quite complex due to the non-deterministic patients' reactions and other related factors to be considered.
- Lack of standardized measures to determine the proportion of factors to diagnose patients with certain type of ailments may be in adequate as this relies subjectively with the physician work experience and educational material.

One major challenge that faces the implementation of DSS for patient's diagnosis is that not all diseases can be subjected to trials and this relies on selective therapies according to the experts [7].

3. METHODOLOGY

The implementation of the DSS applied in this research was developed using the PowerBuilder and Prolog as an inference system. Some of the reason for choosing PowerBuilder is because the Datawindow is patented and allows for rapid application development. It also enable embed Standard Query Language (SQL) in programming language which is more convenient for database handling.

Furthermore, the use of Prolog was selected due to the inbuilt back chain mechanism which contains less procedural concern and it is more domain-oriented.

A total of ten different types of arthritis were identified along with their relevant factors. Different weights was assigned to each factors according to the information provided in the literature review with the largest weight being the dominant factors. In programming the systems structure, the 'forward chain strategy' this contains IF-THEN rules based systems was designed via the PowerBuilder to perform the checks for each condition provided as an ailment by the patient. The response and the outputs was information of diagnosis showing different weighted factors for each type of arthritis and providing recommendations as to what the requirements are for the next procedure. Different factors were evaluated and some diagnosis shared the same factors though with different weights. The range for each arthritis factor was between 2-8 factors. Some of the shared factors possessed different weights due to them having less impact on the selected arthritis. Some of the 10 types of arthritis considered include Rheumatoid arthritis, Knee Osteoarthritis and Hip Osteoarthritis among others.

Figure 2 shows the static structure of this system. The Graphical User Interface (GUI) is used for interaction between the users and the systems. The database includes patients' personal stored information and medical records, while the knowledge base configuration can be edited in the text editor to change the inference facts and how they should be questioned in the GUI. Facts are written to the file system and it is accessed each time the physician run a diagnosis. Java Virtue Machine (JVM) and Interprolog consists of an interface between Power script Business Layer (PBL) and Prolog Inference Engine. The system designed allows the physician or the designated staff to enter the patient's characteristics (information) into the computer systems. By click of a button, computerized generated recommendations and the major types of probable arthritis are obtained.

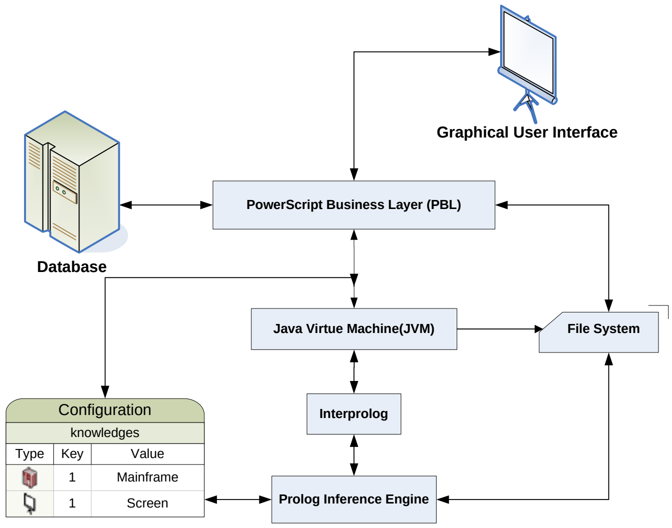

Figure 2: Static System Structure

Figure 3 describes the systems process and data flow as implemented. The initial step requires the medical staff to collect data/ personal information on the patient related ailments and add input into the system and transfer to the Power script Business Layer (PBL). The next step is to transfer the input to the predicate which later will be used by Prolog Inference Engine. Interprolog and JVM enable the communication between PBL and Prolog Inference Engine through file system. The engine can then consult the prolog code file in file system, inference the possible solutions and then return them to PBL. Finally, PBL will transfer these solutions into user-friendly format and display them via the Graphical User Interface (GUI).

3.1 Assumptions

Some of the assumptions included in the design of this research are

1. The 10 forms of arthritis are a representative of the worst cases of arthritis.
2. The factors chosen for each arthritis type represents the major characteristics.
3. Patients coming in for diagnosis have no prior examination of x-ray and radiology test. The criteria utilized excluded any patient with associated radiology or test.
4. For each type of arthritis, there is one dominant factor assigned a 50% chance of influencing the outcome, while others share the distributed weight according to the set diagnosis rules.

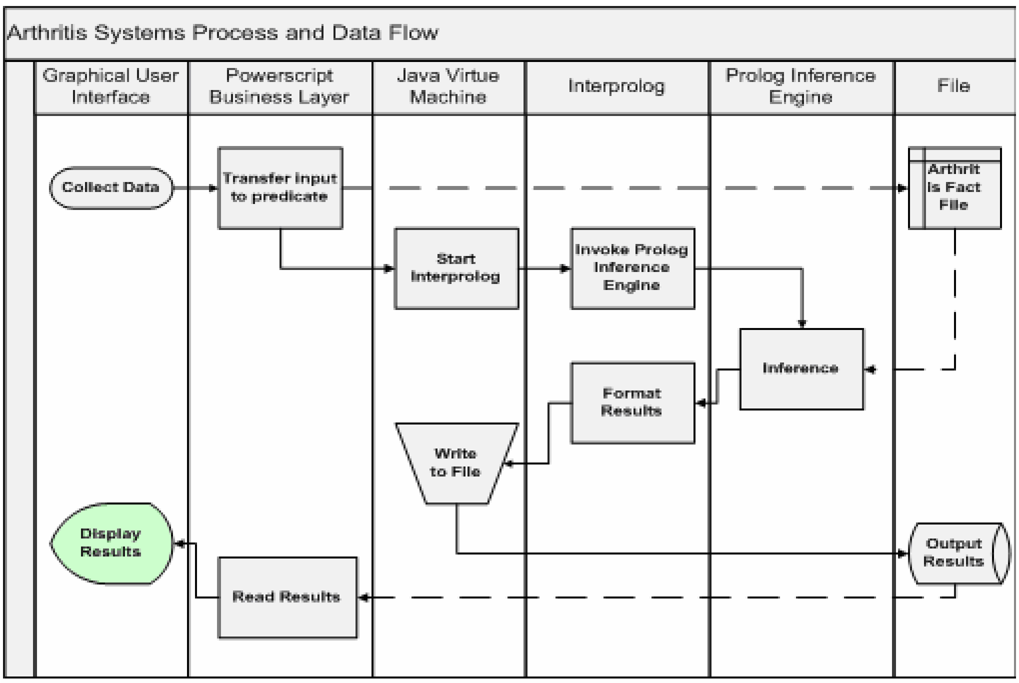

Figure 3: Arthritis System Process Flow

3.2 Medical Diagnostic Errors

The proposed MDDS seeks to reduce the Medical Diagnostic Errors (MDE) based on the following attributes. The clinicians have to select and check the patients related conditions i.e. minimize data entry error. The system provides recommendations based on visual presentation by graph and a pie chart showing the percentages of the probable diseases faced by the patient. The physician also has the benefit to view the patient historical data which included previous medical intervention provided which enhances the decision making process.

4. ANALYSIS

The characteristic of the patients evaluated indicated accurate results based on the underlying developed inferences of the DSS. Data used for representing these factors was generated randomly using the excel worksheet. Figure 4 below shows the data entry and form displaying the patients' information and arthritis factors affecting the patient.

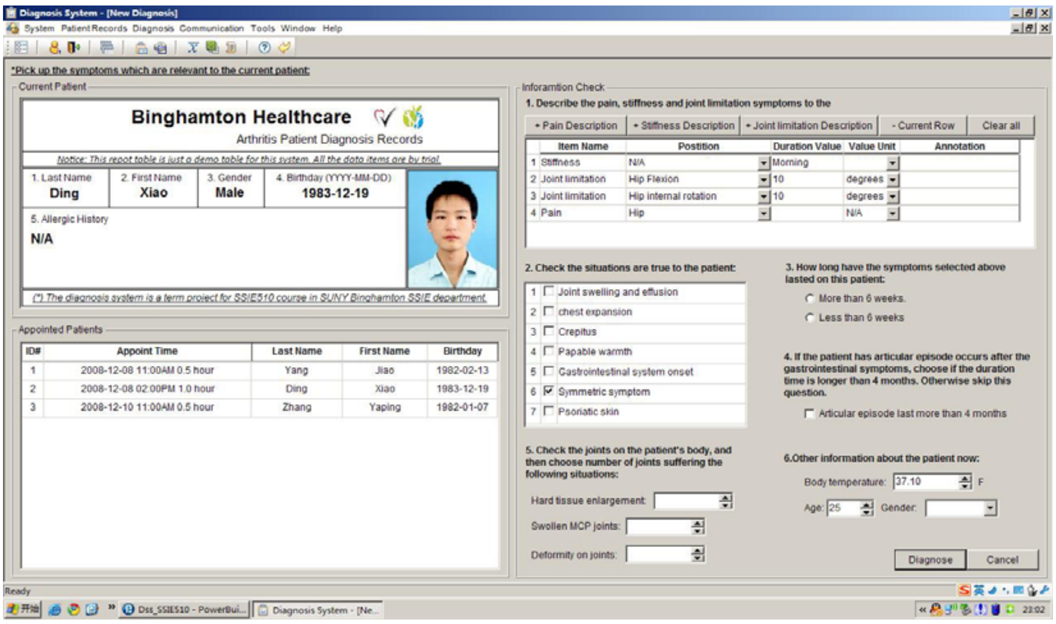

Figure 4: DSS Data Entry Form

The data input for the patients was entered into the system which was then inferred to the set rule based systems within the program. Based on the underlying set of rules utilized correct diagnosis was obtained and the system displayed the correct output as shown in Figure 5. The example (see Figure 5) was a diagnosis for patient who exhibited all the factors common to Rheumatism Arthritis. From the DSS, the recommendation provided by the system was accurate showing that with percentage of each factor accounted for; the physician needs to focus on providing Rheumatology intervention to the patients.

Other condition tested was based on situations where the patients showed more than one characteristic of a certain type of arthritis. The DSS was able to provide the appropriate recommendation. In the case where more than two dominant factors were identified, the DSS recommended further testing such as radiology needs to be conducted due to the different kinds of arthritis identified. The results obtained showed a robust model which can be able to match patients suffering from different forms of arthritis. In addition, the time take for decision making may be faster thus improving the physician performance in providing quality care.

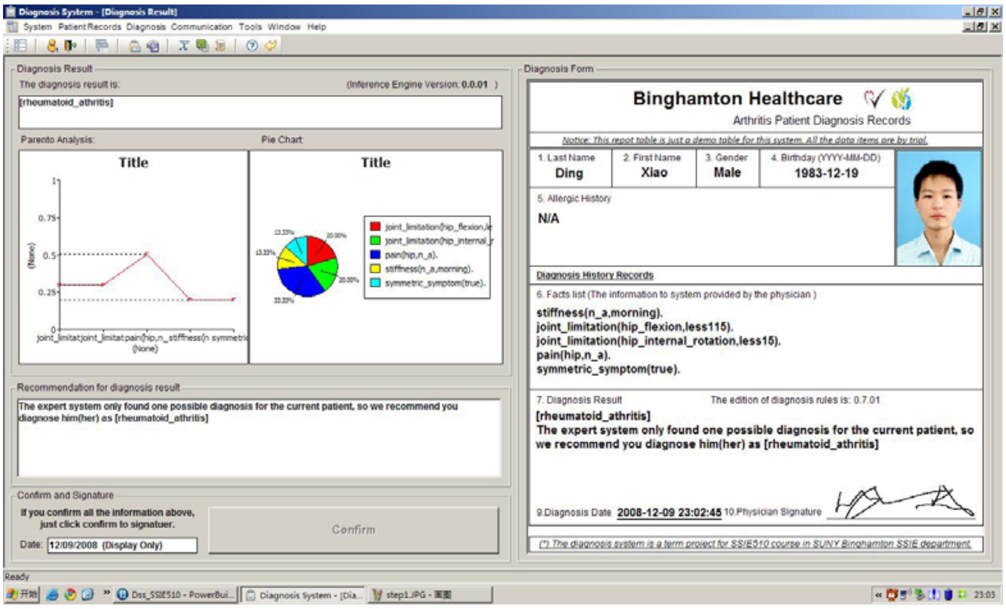

Figure 5: DSS Rheumatology Results

5. CONCLUSION

The DSS are designed to “work with clinicians, and not instead of” [1] pp.3. DSS enables the physicians and medical staff in decision making process according to the recommended options. In addition, it aids in the facilitation and reduction of MDE which may be due to unnecessary health procedures. Moreover, the physician performance is increased and as a result there is increased patient satisfaction, improvement in the patient-physician relationship and an increased in patients throughput. DSS system if well designed has the ability to be utilized in modeling different kind of diseases. Furthermore it can be integrated with other Industrial Engineering tools such as simulation to enhance its performance and generated conclusive results on specific application. Safety, accuracy and timely interventions by the physician are major concerns among the patients and this may impact their lives. Therefore, DSS modeled should be an accurate representation of the patients' characteristics, valid and credible. In addition, it should not be applied for any diagnosis unless verified as not being harmful to the patients.

5.1 Future Work

The concern of accurate method employed in systems or procedural design needs to be addressed. The main challenge is due to the several factors which contribute towards the diagnostic rules; there has been lack of an efficient system which encompasses all the factors. A proposition in this case, any expert system or DSS developed should incorporate all factors. In addition, a standard measure on how to allocate the weights (probability) for the related factors needs to be determined by medical experts within the arthritis domain. Another possible proposition is to integrate the DSS systems to contain the resource utilization required within the system. For instance if a patient is a diagnosed with a certain ailment, necessary requirements in terms of laboratory staff and nursing staff can be estimated and determined. This would improve the service offering and reduce the waiting time and efficient resource utilization of patients. Usability testing of the systems by experts in the healthcare domain is a necessary step that would seek to validate and enhance the credibility of DSS model proposed. The related impacts of DSS for the patients can be explored to identify the impacts on the health system. There has been improved information sharing via the internet and due to the advancement in both hardware and software development of support systems for the patients use. Decision on their output may expose an interesting idea and may change the physicians' interventions and on the other hand, may empower the patients to get involved in their health lifestyle.

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An Analysis of Textured Features Fabricated by FDM Rapid Prototyping Process

T. D. Phan[1] and S.H. Masood[2]

[1,2]Industrial Research Institute Swinburne, Swinburne University of Technology, 545 Burwood Road, Melbourne, VIC 3122 Australia.

ABSTRACT

This paper presents a study on what accuracy level could be achieved when fabricating textured surfaces by the Fused Deposition Modelling (FDM) rapid prototyping systems. The study is based on the evaluation of a variety of textured surfaces fabricated in ABS material on a commercial FDM machine. The analysis of the results shows that the FDM parameters have a great influence on the surface roughness as well as geometric and dimensional accuracy. The results obtained can be used to make decision on what types of textured features, according to sizes and geometries, can be made with fused deposition modelling process.

Keywords: Textured Surfaces, Fused Deposition Modelling, Rapid Prototyping Systems, Surface Roughness, Geometric and Dimensional Accuracy

1. INTRODUCTION

Fused Deposition Modeling (FDM) is one of many rapid prototyping processes, in which part is made by depositing molten thermoplastic extruded from a nozzle of a heated extrusion head. Material in filament form is drawn into the head, which moves horizontally, tracing the exact cross-section of each layer. It is commonly used to make prototypes of newly designed products. Compared to conventional manufacturing processes, FDM has dramatically reduced the manufacturing time. Significantly, FDM is considered among a few rapid prototyping systems that offer the potential to fabricate textured surfaces directly.

Recent years have seen a substantial amount of research in the area of layered manufacturing process. These works have included consideration of part orientation or build direction, support structures, layer thickness, and layer path planning, in order to optimise build time, surface finish, geometric and dimensional accuracy, or part strength (Armillotta, 2006). Whereas, Tong *et. al.* (2003) reported their work on part building orientation optimisation with managing to trade off between surface finish, part accuracy and building time. Depending on the orientation chosen it can be responsible for poor surface finish, increased build time, increased support structure, as well as geometric and dimensional inaccuracy. They developed a procedure to reduce the complexity of part orientation by automating the orientating step.

Ziemian and Crawn (2001) have proposed a new slicing technique which is called adaptive slicing. It refers to a situation where the layer thickness varies in different regions of the part, allowing thicker layers where surface accuracy is not important, and thinner layers where it is crucial to minimize the stair-step effect. Han *et. al.* (2003) studied the effect of road width and air gaps. They found that increase of road width will decrease the build time. However, the selection of a road width is constrained by head speed, roller speed, contour curvature, and nozzle size. Typically the road width is usually required to have a width that is 1.2 to 1.5 times the diameter of the nozzle.

Ghorpade *et. al.* (2007) studied volumetric error which is responsible for the formation of geometric inaccuracy and poor surface finish. It is defined as a ratio of actual volume of material consumed in the creation of the part to the volume of material specified in its design model. They stated the volumetric error can be reduced by decreasing the layer thickness and orienting the part at the appropriate angle, however, slicing of CAD model with a very small slice thickness leads to large build time. Pandey *et. al.* (2003) have done a similar study, in which they found that the staircase effect cannot be eliminated on a RP part completely. Refinement of layers improves the surface finish of the part, but it increases the build time, and the cost of the prototype is directly governed by the build time.

Besides process parameters tuning and build orientation optimization, other aspects of process planning of RP techniques, such as STL data file generation and correction has also been studied in detail for process improvement. Researchers at several universities worldwide, and especially in the USA and Europe, have developed software tools for rapid prototyping in the areas of STL file generation. For instance, Armillotta (2004) proposed a solution which uses displacement mapping to add geometric detail to STL part models. A software tool has been developed to apply displacement maps on triangle meshes by a procedural displacement strategy designed as an extension of existing approaches to graphical texturing. The accuracy of a rapid prototyping machines is usually given in the machine specification as a ratio of an error per unit length. For instance, the tolerance of FDM Titan machine has been quoted as +/-0.0015 mm/mm for part sizes over 127 mm (Plasteurope News, 2001). However, such number cannot fully describe the accuracy of the machine. Users are still unable to determine whether the part made by a specific RP machine can meet the dimensional accuracy and surface finish requirements.

Nevertheless, there are not many published literatures on the accuracy analysis of latest commercial FDM systems when fabricating parts with textured surfaces. For that reasons, the purpose of this study is to investigate and evaluate the influence of different process parameters of the FDM rapid prototyping process on the dimensional accuracy as well as the quality of surface finish of parts with macro-scale textured features.

2. MATERIALS AND METHODOLOGY

Of the various build materials available for the FDM Vantage X, only the P400 Acrylonitrile Butadiene Styrene (ABS) plastic was used during experimentation for model material, as one of the more robust and multi-functional materials, and ABS-400R as the support material. Another reason is that almost all systems in the FDM line-up offer ABS as a material option, and nearly 90% of all FDM prototypes are produced in this material. It is also reported that the ABS prototypes demonstrate 60–80% of the strength of injection moulded ABS (Grimm, 2003). Other properties, such as thermal and chemical resistance, also approach those of injection moulded parts. This makes ABS a widely used material for functional applications. A fused deposition modeling machine, FDM Vantage X. was used to fabricate actual generic textured surfaces with simple features, hemisphere and cube. The process parameters changed were tip diameter, test parts orientation, layer thickness, slice height, road width, raster angle and filling style. Then, the accuracy and surface roughness of those features were measured. Finally, the evaluation of experimental measurement result was performed. It provides information on what accuracy level could be achieved when fabricating parts with textured surfaces by FDM systems. The statistical analysis of the results shows that the selected FDM parameters have a great influence on the surface roughness as well as geometric and dimensional accuracy. The results obtained can be used to make decision on what types of textured features, according to sizes and geometries, can be made with Fused Deposition Modeling Process. This means minimisation of the time spent for evaluating and selecting of a suitable rapid prototyping process.

3. DESIGN AND FABRICATION OF TEST PARTS

All the test parts were modeled in a commercial CAD system with the aim to identify the quality characteristics of texturing surfaces built by the FDM Vantage X process, including geometric and dimensional accuracy as well as surface roughness. Figure 1 shows the CAD model of a test part containing all features. The overall dimensions of the prototype are 55x80x10mm. Two different feature shapes with different feature size (b) and feature height (h) were selected: One is hemisphere shape and the other is cube shape. The feature size range is from 2.0 to 4.0mm, and the range of feature height is between 1.0 to 2.0mm. Besides that, the spacing between two features is chosen as 1.0mm according to the guideline in Armillotta (2006). STL geometry file was then generated in order to import to FDM system and build the prototypes layer by layer. STL files mesh resolution has been set to 1/5 of minimum feature size (0.2mm); as a result the number of generated triangles is 90922 with the file format as Binary.

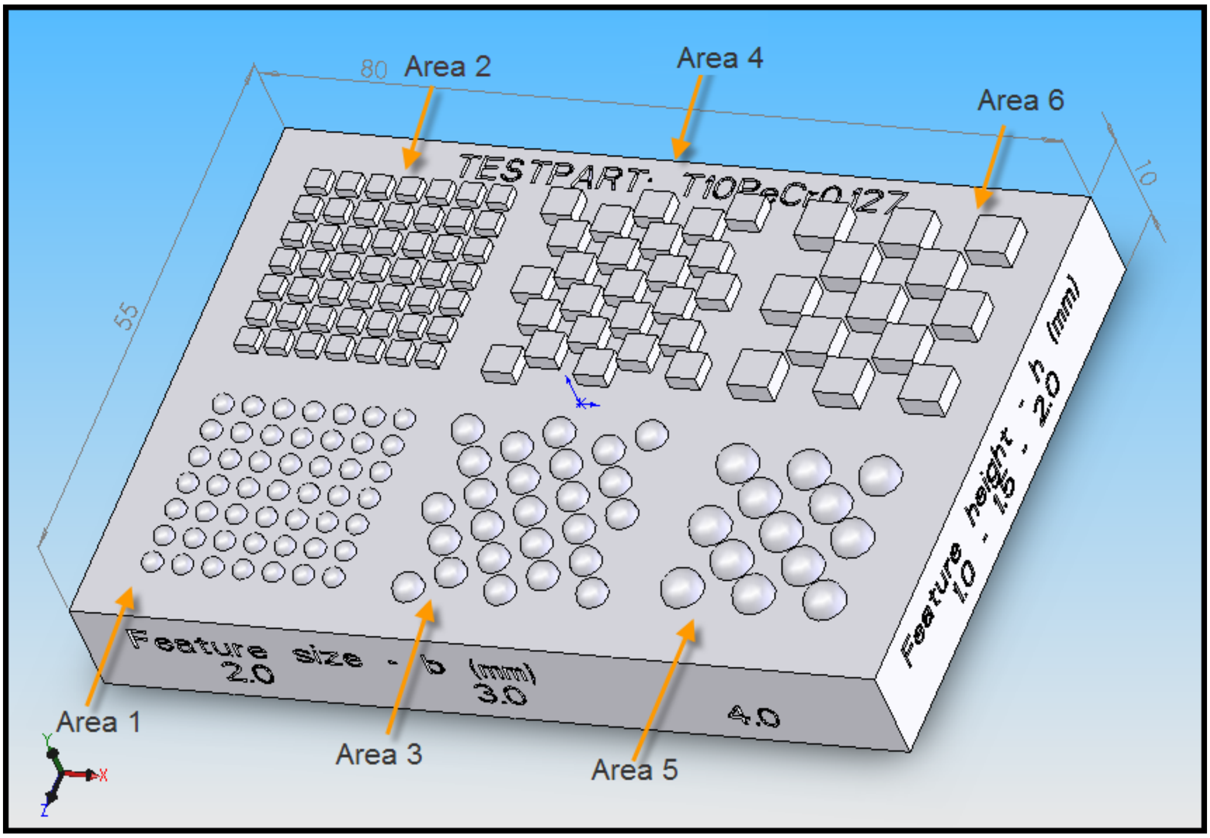

Figure 1. A test-part was successfully modelled

In consideration of the accuracy and surface finish of the textured features modeled, there are several process control parameters that are likely to affect the properties of FDM prototypes. This paper only focused on the parameters in the pre-processing stage. These selected parameters were: build orientation, tip diameter, layer thickness, road width, slice height, raster pattern and raster angle. Each of these seven process variables were studied at three levels as can be seen in the fish diagram of Figure 2. As a limit in this study, the influences of process parameters in following stages were neglected: CAD modelling stage, fabrication stage and post processing stage.

The first thing is to set the orientation in which the testing parts will be built. The chosen orientation will affect how the final part comes out because the FDM builds up the model in layers along the z-axis. Basically, proper orientation of the STL model is necessary to minimize or eliminate supports. However, support minimizing is not considered as an important factor in this study as the main objective is to focus on the quality of surface roughness and geometric and dimensional accuracy of textured surfaces. Consequently, three candidate build orientations were first defined as parallel, perpendicular and 45 degree to XY plan.

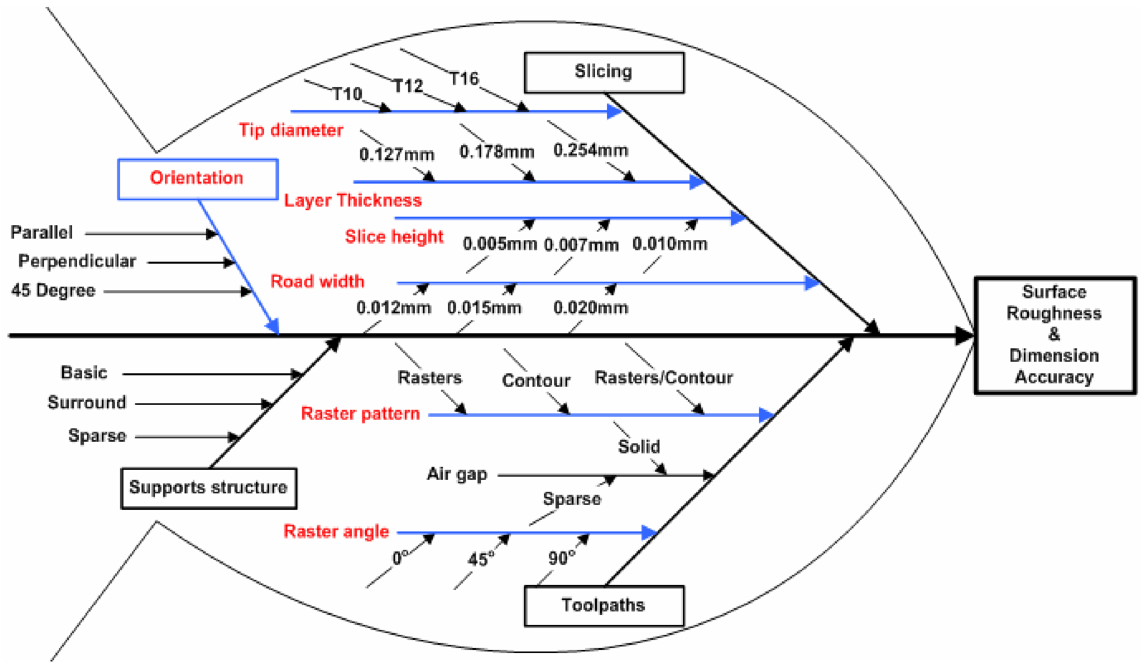

Figure 2. Selected FDM process parameters to be changed

As shown in Figure 3, "Parallel" indicates the building process is parallel to the X-axis and parallel to the Y-axis, whereas, "perpendicular" indicates the building process is parallel to the X-axis and perpendicular to the Y-axis, and "45 degree" indicates the building process is 45^{o} to the X-axis and parallel to the Y-axis.

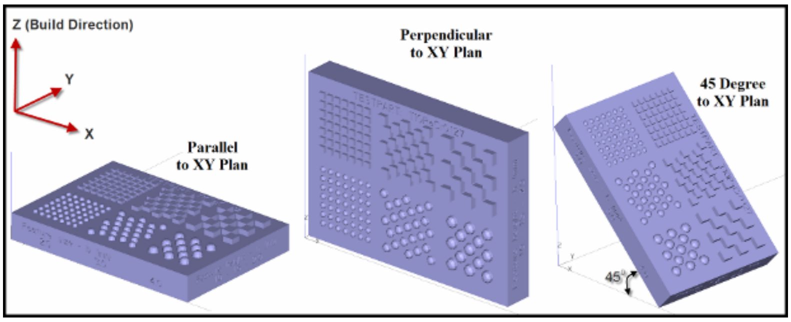

Figure 3. The selected building deposition orientations to XY plan

Each of the three different nozzle tip sizes on the FDM Vantage X (T10, T12, and T16) has a recommended layer thickness, 0.127mm, 0.178mm and 0.254mm respectively. In relation to the road width, also called bead width, the FDM process uses a closed path that limits the minimum feature size to two passes of the extrusion tip. Thus, most FDM prototypes are constrained to a minimum feature size that is twice the road width. For the FDM Vantage X system, it can vary from 0.012mm to 0.020mm. Specifically, the tip diameter T10 has an inside diameter of 0.127mm, and a road width range from 0.002 to 0.008mm; whereas T12 tip diameter has an inside diameter of 0.178mm, and the range of road width is 0.012 to 0.028mm. Thirdly, the tip diameter T16 has an inside diameter of 0.254mm with 0.016 to 0.035mm range.

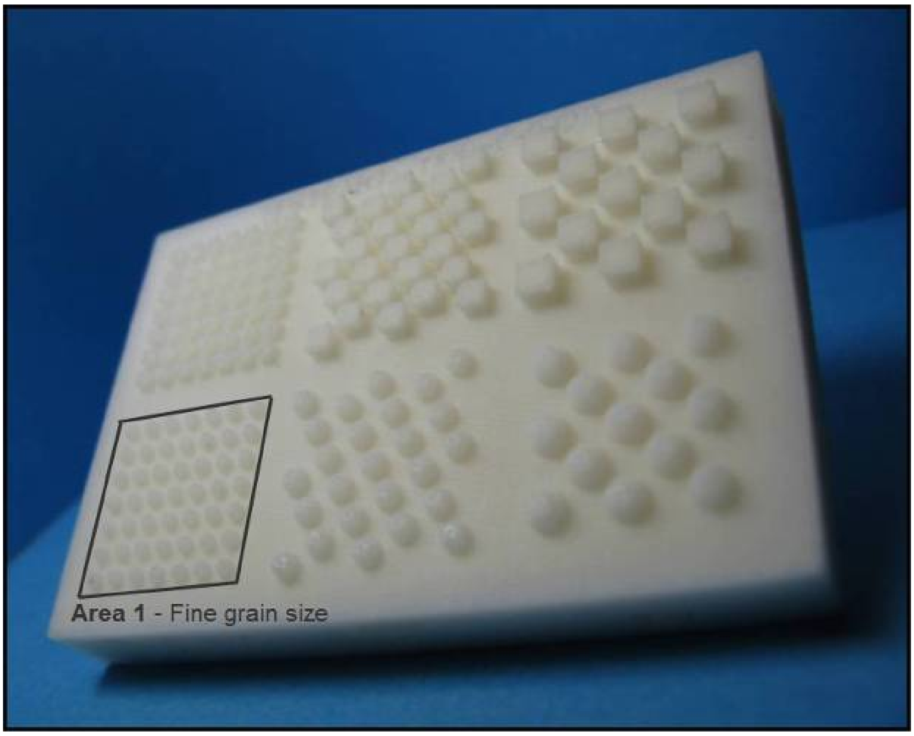

Figure 4. Testpart01 fabricated on FDM Vantage X

Following the slicing and creating of supporting structure, tool-paths are needed to build each layer. Each perimeter or boundary in a layer is a closed loop with a start and end point. Once the perimeters are defined, the internal portion of the layer is filled by roads of selected width and thickness in one of following ways: (1) Raster pattern: A raster motion of the filament head back and forth is used inside the defined perimeter regions to fill the entire area; (2) Contour pattern: Several closed loop contour motions of the filament head inside the defined perimeter region is used until the selected region is completely filled; (3) Contour and raster pattern: A combination of the first two approaches such that the deposition of the region, defined by the perimeter, is followed by deposition of material by a few contour motion followed by raster filling of rest of the internal area. The raster pattern approach is used most frequently due to its speed and the ability to change the direction of raster motion in adjacent layers. Typically, alternate layers are built with raster angle at 0°, 45° or 90° to one another.

The building process may take several hours depending on the size and the number of parts required. For example, Figure 4 shows a finished prototype (Testpart 01), which was created with selected process parameters: parallel build direction, T10 tip diameter, 0.127mm slice thickness, 0.005mm slice height, 45 degree raster angle, and rasters pattern style. It was successfully built after almost 10 hours 58 minutes. There were a total of nine prototypes with textured features fabricated on FDM Vantage.

4. RESULTS AND DISCUSSIONS

Geometric and dimensional accuracy as well as surface finish of components are the most important quality characteristics in layered manufacturing processes. Thus, upon completion of the fabrication process on FDM machine, prototypes with textured features were measured and verified by using micro vernier caliper and TalysurfEE surface measuring machine. The objective was to find the deviation in the X and Y-axis accuracy, and additionally the deviation in accuracy of the various individual geometric features on the test-parts. The measurements included features size, features height and surface roughness.

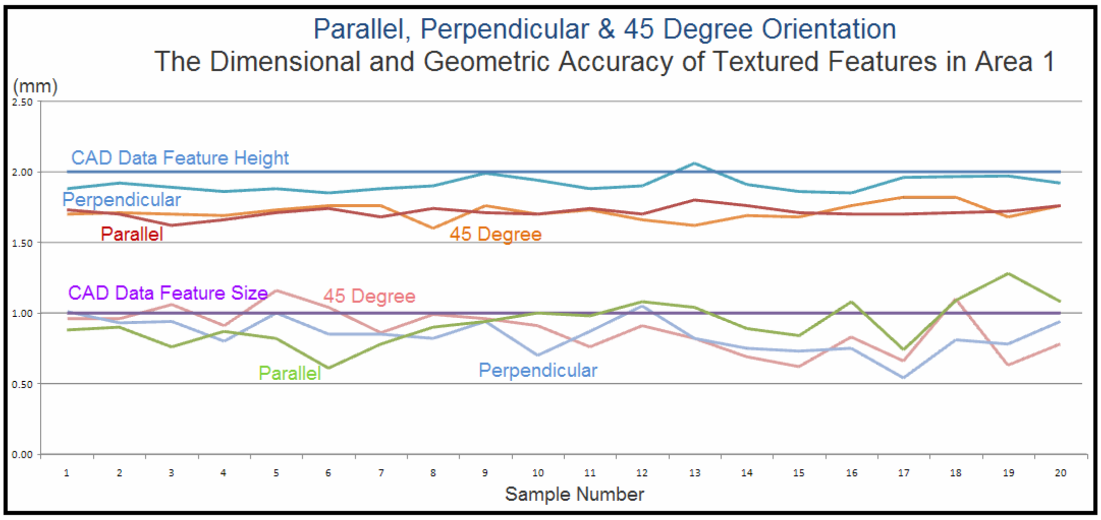

Figure 5. Plots of compared data between measurement and CAD model for Area 1 (Figure 4)

Geometric and dimensional accuracy can be quantified as the average absolute deviation between measured points from the actual part surface and the associated nominal part surfaces as represented within the CAD model (Ziemian and Crawn, 2001). As a consequence, the measured data points were compared to computer aided design (CAD) data to extract the geometric and dimensional error. Figure 5 shows the results of this comparison for a range of prototype sampling. The results are tabulated and the analysis of measured data indicates that the fabricated fine grain textured features have an accuracy deviation of about 14.28 %. This was attributed to be partly caused by the shrinkage of the material. The best achievable accuracy based on this material is ±0.1 to ±0.02 mm deviation as compared to the design dimensions on CAD models for the medium grain features. Summarily, it was observed that the FDM is least suitable in building very fine features in terms of dimensional and geometric accuracy. For medium and large sized features, the results are more accurate.

The most obvious limitation of FDM is surface finish which is caused by the stair stepping effect on curved and sloping surfaces. Generally, surface roughness is a very difficult parameter to quantify for a number of reasons. These measurements are also dependent on the direction in which the roughness is measured. In this paper, average roughness values - Ra of the base surfaces, including top, bottom and side walls, of the testing models were measured using a TalysurfEE device.

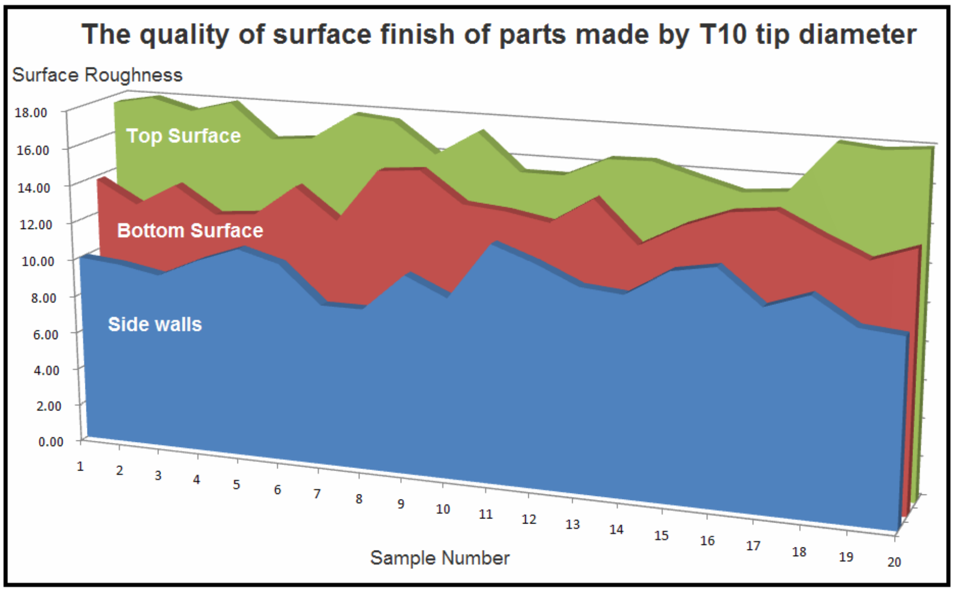

Figure 6. Surface roughness (Ra) of parts surfaces made from T10 tip

Layer thickness was the most important parameter to affect surface roughness. If the deposition layer is thinner, then better surface roughness will be obtained. The thicker deposition layer represents the higher stacking filament, which will obviously affect the final surface roughness. Figure 6 shows the average surface roughness value of the part fabricated by T10 tip diameter, which has the smallest layer thickness (0.127mm). The results show that testing parts made by T10 nozzle are the most superior of the surfaces. As the layer thickness increases, the roughness of the surface also increases. Although improving of surface finish is possible with smaller road widths and thinner layers, the top, bottom and side walls of the fabricated parts with textured surfaces will still show the contours of the build layer. Consequently, the model has to have a secondary operation like hand finished to go to a better surface finish in all cases.

5. CONCLUSIONS

This study has involved the design of 3D solid models of test parts with different textured surface features for accuracy evaluation. Then, the prototypes with textured surfaces have been successfully built by a commercial FDM system, FDM Vantage X, using ABS-400 as the part material. The measurement results are used to find the relationship between part accuracy and manufacturing process parameters. It was found that the selected FDM process variables have a significant effect on the textured surface accuracy. As a result, when making decision on what types of textured features can be fabricated with the latest fused deposition modelling systems, the following points need to be considered beforehand to achieve the best possible results:

- By using the smallest tip size, which allows smallest road width values, features with rounded corners like semi-hemispheres could be fabricated with an acceptable geometric and dimensional accuracy and surface finish if the smallest feature size is not less than 1.5mm. Features with sharp edges like cubes should have smallest feature size not less than 2mm to obtain similar accuracy and surface quality.
- With both types of features, the tip size diameter and the building orientation in vertical direction are the two most important parameters that affect the geometric and dimensional accuracy of the textured features as well as the quality of surface finish.
- Using the smallest tip possible and choosing an appropriate orientation will give the best result for textured surfaces. In addition, the use of smaller slice thickness also produces better surface finish, but it will increase the time to fabricate. For that reason, usually surfaces and features on any RP part are hand finished to obtain the desired surface quality.

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Adoption of an Exact Method for Vehicle Routing Problem

Chang Jia Ming, CKM Lee[1]* and Shaligram Pokharel[2]

[1.] School of Mechanical and Aerospace Engineering, Nanyang Technological University, 50 Nanyang Drive, Singapore
[2.] Department of Mechanical and Industrial Engineering, College of Engineering, Qatar University, Doha, Qata

ABSTRACT

Vehicle Routing Problem (VRP) is a challenging problem faced by logistics companies and organizations which engage in the delivery and collection of goods. The basic vehicle routing problem involves finding a set of optimal routes for a fleet of vehicles such that it meets the requirements of the customers; all the operational constraints are satisfied and the total transportation cost is minimized. When capacity constraints are applied to the basic VRP, it is described as Capacitated Vehicle Routing Problem (CVRP). In this paper, CVRP is modeled with Integer Programming and solved with an exact algorithm called Branch and Bound. Subsequently, computational experiments are performed on the Integer Programming model to determine the computational performance for solving CVRP with different customer sizes, vehicle capacities and customer delivery demands. Simulated data has been used to test the model. The results show that computational time is significantly long when customer size exceeds 20. The results also show that computational performance is faster for instances when larger vehicle capacities are used in the model. Further analysis shows that increased customer delivery demands, similar as vehicle capacity, can have lowest elapsed runtime.

Keywords: Vehicle Routing Problem, Linear Programming, Branch and Bound, Exact Methods

1. INTRODUCTION

Vehicle routing and scheduling problems are optimization problems in the field of operation research. Routing is the assigning of a group of customer to be served by a vehicle from a depot. Scheduling is the sequencing of each customer to be served in each route. These problems are found to be applicable to real world distribution problem because of its practical relevance and complexities involved. Practical applications of the Vehicle Routing Problem (VRP) are numerous and encompass many spheres of logistics distribution.

With the increasingly complex and demanding environment, companies are confronted with more challenges in planning. Hence, companies have to adopt fast and cost effective routes in order to meet the rigorous demands of customers and logistics operations. Advancements in computing and algorithms have aided companies to solving transportation problems. These algorithms are classified into exact methods and heuristics methods. Many works done on exact methods found that it gives optimal solutions (Toth and Vigo,2002; Laporte, 1992). On the other hand, many studies (Yurtkuran and Emel, 2009) on the problem have been done through development of meta-heuristics in recent years. They have yielded some good results that are close to the optimal solutions. But the constraints are complex and hard to implement in meta-heuristics. With a consistent and effective route design methodology, vehicles can be managed at optimal levels to improve organizational goals and manage cost cutting measure effectively. The objective of this paper is to examine the concept behind the integer linear programming in solving optimization problems and apply an integer linear programming model in solving the Vehicle Routing Problem.

The following section in the paper describes the background of the vehicle routing problem and the objectives of this study. Section 2 presents an overview on the relevant literature on Vehicle Routing Problem and provides an insight into the existing solution methodologies. The integer programming model for capacitated vehicle routing problem (CVRP) is proposed in Section 3. Section 4 shows the application of the model to solve a case study problem using branch and bound method in LINGO® software. Conclusions are given in Section 5.

2. LITERATURE REVIEW

This section describes some of the main derived problems of VRP and the current methodology in solving the VRP. The derived problems and their connections with VRP include capacitated VRP (Moghaddam et al.,2005; Belenguer and Benavent, 2001), VRP with backhaul (Vigo, 2002), and VRP with Time Windows(Tan et al., 2001; Qureshi et al.,2009) and Multi Depot VRP (Garey and Johnson, 1979). Among VRP, capacitated VRP can be testified by the numerous literatures which are demonstrated in documentations of various contexts within distribution management and logistics, including case studies on oil delivery problems (Martin and Yves, 1984). It has been found that existing methodologies for the CVRP can be generally classified into exact methods (Toth and Vigo, 2002; Laporte, 1992), heuristics (Yu et al., 2009; Mester and Braysy, 2005) and meta-heuristics (Yurtkuran and Emel, 2009). Due to the complexity of VRP, using exact methods to solve them is quite practical for instances of no more than a few jobs and/or vehicles. Exact methods propose to search for the all the possible solutions until the best one is found. These exact methods can be broadly classified into branch and bound, mixed integer programming and integer linear programming. An application of linear programming (LP) to solve the problem of providing a coordinated vehicle scheduling and routing system for delivery of consumable products to customers of the Du Pont company was discussed by Fisher et al. (1982). The primary issue was to determine delivery routes for the trucks to the company's clients in various regions of the country. An LP model was implemented and it was reported to reduce $200 million cost for Du Pont. There is another case of Air Products Corporation facing a similar problem (Bell et al,, 1983). And it was solved by using a more complex mathematical model. LP formulation was also proposed for use in the determination of vessel traffic under known supply and demand constraints in the work of Sambracos et al.,(2004). The objectives are to minimize the total fuel costs and port dues. Therefore, it can be seen that the applications of LP techniques are used in solving various types of complex VRP. Algorithms for solving integer linear programs include: cutting-plane method, branch and bound, branch and cut, and branch and price.

If the problem has some extra structure it may be possible to apply delayed column generation. Further readings can be found in Padberg (1999) and in Beasley (1996). For small instances of CVRP, the branch and bound method has proved to be the best (Francisco et al., 2002). In practice, the best exact algorithm can give the best result to problems involving less than 50 nodes. However, how many customers should be set in vehicle routing computation? What capacity of the vehicle should be set so as to meet the demand? How do the setting of customer demand affect the computation time? Those questions need further investigation and those issues are discussed in this paper.

3. ADOPTION OF EXACT METHOD FOR CVRP

In this section, the mathematical model for CVRP will be discussed. The type of formulation used here is known as the vehicle flow formulation (Vigo, 2000) which is frequently used for modeling vehicle routing problems. The symbols and set notations which are used in the integer programming in the model are shown below:

V: Set of all the customer locations

V_0: Set of all customer locations and includes the location of the depot (denoted by customer 0)

d: Distance between any two customers' locations

x: Decision variable in binary value; 1 if vehicle travels from customers i to j, 0 otherwise

i, j : denotes customers nodes and represents customers links

D: delivery demand of customers

L_i: amount of deliveries made along the route at customer i

L_{max}: Maximum load that vehicle can carry

Z: Total sum of distance traveled by the vehicles for a set of routes

Assumptions:

- Vehicles follow a symmetric route, $d_{ij} = d_{ji}$
- Fleet of vehicles has uniform capacity of which is indicated by L_{max}
- Undirected graph, no customer precedence or priority

With the exception of capacity constraints conditions, other constraints on vehicles are not imposed on the problem.

Objective Function

The objective of this model is to minimize the total distance travelled by a fleet of vehicles

$$\text{Minimize } Z = \sum_i \sum_j d_{ij} x_{ij} \quad \forall i, j \in V \ldots \ldots (1)$$

Subjected to the following constraints:

Customer Constraints

$$\sum_i x_{ij} = 1 \ldots \ldots \quad (2)$$

$$\sum_j x_{ij} = 1 \ldots \ldots (3)$$

Both constraints (2) and (3) ensure that all the customers are visited exactly once. This will prevent vehicles making two trips to the same customers.

$$\sum_i x_{ii} = 0 \ldots \ldots (4)$$

Constraint (4) ensures that a vehicle does not travel to the same location.

Vehicle Constraints

$$\sum_j x_{j0} - \sum_j x_{0j} = 0 \ \forall i \in V_0 \text{ and } j \in V \ldots \ldots (5)$$

Constraint (5) ensures that the same vehicle enters and leaves from each customer locations which it serves.

Capacity Constraints

$$\sum_{i} D_j x_{ij} \leq L_{max} \dots \dots (6)$$

The sum of the load of the vehicle at any instant of time along the route should be less than or equal to the maximum capacity of the vehicle. This constraint prevents the overloading of the vehicle.

Variable Constraints

$$x_{ij} = 0 \; or \; 1 \dots\dots(7)$$

x_{ij} is the decision variable. Constraint (7) imposes binary condition on the variable x. If a vehicle makes a trip from customer *i* to customer *j*, it will be 1. Otherwise, it will become 0. The connection of route between the two customers will not be considered.

$$L_j \geq 0, \forall j \in V \dots \dots (8)$$

The variable *L* is constrained to be only positive values by the above constraint.

4. CASE EXAMPLE

4.1 Description of Case Study

The purpose of the case example is to illustrate the application of the model in solving a case of CVRP. The case example is for a local company in Singapore which distributes imported health products to health and nutrition retail stores.

The distribution network consists of a central depot and a set of these retail stores which are dispersed around Singapore. The stores will be termed as customers. The company just secured a deal with several nutrition stores to sell a new health product to them. However, it needs to find better transportation arrangement to make deliveries to its customers. It is planning to hire some rental vehicles. Before that, it wants to determine some crucial figures such as the transportation distances and the number of vehicles it needs for transportation planning.

4.2 Data Collection

The health products are packed in a box of 12 bottles of 1.5 liters. The order quantities to be delivered are collected and shown in the Table 1.

Table 1: Delivery demand of each customer

Customer location	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Customer Delivery Demands (units)	0	15	30	16	23	11	25	15	28	10	15	10	14	12	19	11	12	26	17	12	22

The direct distance between each customers and customers with the depot are expressed in the distance matrix as shown in Table 2 and they are expressed in terms of kilometers, km. For instance, the distance between customers C1 and C3 can be located from customer location column C3 and customer location row C1. Thus, the distance between the two customers is 10 km.

The maximum carrying capacity for each delivery van is 60 units. The optimum number of the delivery van needed for the case study is determined by the model formulation and will be obtained from the solution results.

Table 2: Distance between customer locations including depot (in km)

	Depot	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19	C20
Depot	0	12	16	17	21	17	15	14	16	20	18	17	18	20	19	16	19	17	22	23	14
C1	12	0	7	10	16	11	12	6	11	10	16	10	14	15	14	16	15	15	20	22	8
C2	16	7	0	6	10	6	12	7	10	11	13	4	9	8	10	16	9	15	14	15	10
C3	17	10	6	0	8	11	8	6	4	6	8	5	15	10	5	12	11	10	9	12	8
C4	21	16	10	8	0	10	15	12	6	4	12	6	12	5	8	19	8	16	5	6	15
C5	17	11	6	11	10	0	18	12	15	13	18	6	3	7	15	22	4	21	16	18	15
C6	15	12	12	8	15	18	0	6	4	13	7	13	22	18	8	4	19	4	16	19	3
C7	14	6	7	6	12	12	6	0	5	12	10	8	15	13	9	10	14	10	15	17	3
C8	16	11	10	4	6	15	4	5	0	9	5	10	18	14	4	8	16	6	12	15	4
C9	20	10	11	6	4	13	13	12	9	0	8	7	16	8	5	16	12	12	3	6	13
C10	18	16	13	8	12	18	7	10	5	8	0	12	22	15	3	8	18	4	10	13	9
C11	17	10	4	5	6	6	13	8	10	7	12	0	10	5	9	17	7	15	10	12	11
C12	18	14	9	15	12	3	22	15	18	16	22	10	0	8	18	25	5	24	18	18	19
C13	20	15	8	10	5	7	18	13	14	8	15	5	8	0	12	21	3	19	20	10	16
C14	19	14	10	5	8	15	8	9	4	5	3	9	18	12	0	10	15	8	8	11	9
C15	16	16	16	12	19	22	4	10	8	16	8	17	25	21	10	0	24	3	18	21	8
C16	19	15	9	11	8	4	19	14	16	12	18	7	5	3	15	24	0	21	13	12	17
C17	17	15	15	10	16	21	4	10	6	12	4	15	24	19	8	3	21	0	15	18	8
C18	22	20	14	9	5	16	16	15	12	3	10	10	18	20	8	18	13	15	0	3	16
C19	23	22	15	12	6	18	19	17	15	6	13	12	18	10	11	21	12	18	3	0	19
C20	14	8	10	8	15	15	3	3	4	13	9	11	19	16	9	8	17	8	16	19	0

4.3 Modeling with LINGO

The integer programming (IP) model is coded using the LINGO mathematical modeling language. First, the sets e.g., customer notations used in the IP model are declared using SET command in the SET section. It is followed by the construction of the objective function and constraints using LINGO syntax. Next, the data for the illustrative case study are entered as input in the dataset section. Lastly, the LINGO program compiles; checks the IP for any logical and syntax error and solves it. Extended solver, branch and bound, is implemented during the solving process. LINGO displays the solver status as shown in Figure 1 while the IP is solved. After the global optimum is found, the solver status window will display the final global optimum solution and the computational timing. The model is run on Intel Core 2 Duo CPU 2.66 GHz and 2GB RAM.

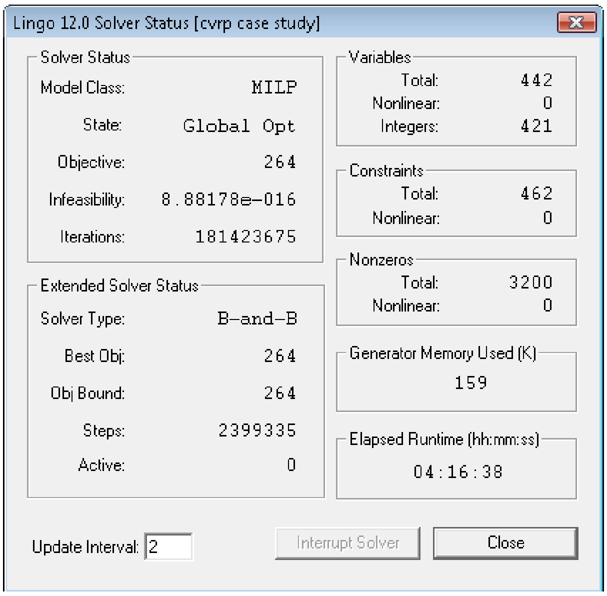

Figure 1: LINGO Solver Status

A representation of the solution report after running the LINGO program is as shown in Figure 2. The first column represents the decision variable. The second column indicates the corresponding values. The third column represents the corresponding distance between the respective nodes.

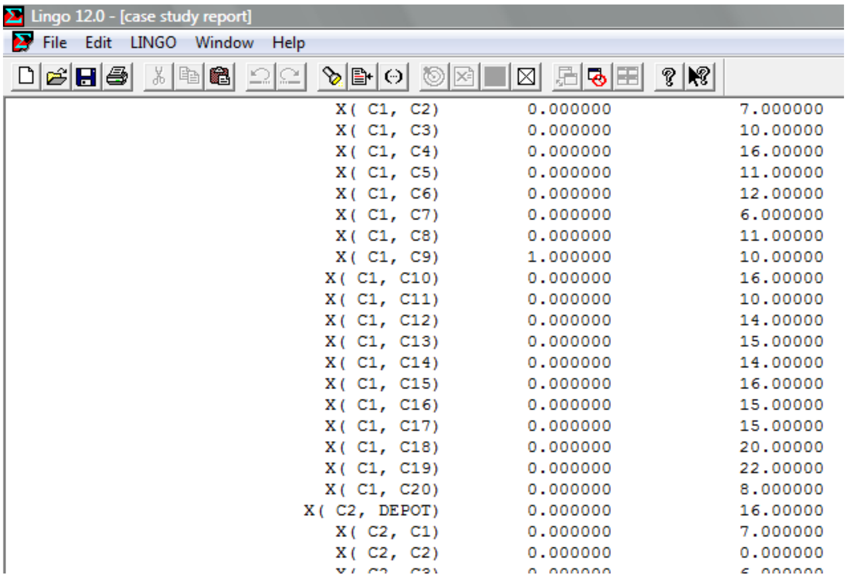

Figure 2: LINGO Solution Report

The non-zero values i.e., value of 1 in the second column for the decision variables X in the Figure 2 indicate that it is a feasible route in the optimized set of routes. For instance, if the value of X (C1, C9) = 1, it means that the vehicle has travelled from customer node 1 to customer node 9 and the distance traveled is 10 km which is in the corresponding row. Table 3 shows the result from LINGO the vehicle route from depot.

Table 3: Results from LINGO Solution Report

Route	Route Direction	Distance Travelled (in km)
1	Depot →C1→C9→C18→ C19→ Depot	51
2	Depot→C2→C5→C12→Depot	43
3	Depot→C7→ C3→C8→Depot	40
4	Depot→C11→C4→C13→C16→Depot	50
5	Depot→C15→C6→C20→Depot	37
6	Depot→C17→C10→C14→Depot	43
Total distance travelled:		264

4.4 Computational Experiments

In this section, the exact method was tested on different sets of CVRP instances with varying customer sizes, vehicle capacities and customer demands to determine the computational performance shown in Table 4. The distances between customers were not varied as the small geographical landscape of Singapore is well represented by the range of 5 to 25 km in the test data. In addition, distance constraint is not imposed. A total of 3 sets of variations and 48 test instances were generated. The test data of the 48 test instances were randomly generated using random number generator and they were normally distributed to closely simulate to the data from the company. The same objective, minimization of the total distance travelled by the vehicles, is used for solving the test cases.

Table 4 Experimental setup

	Number of Customers	Maximum Vehicle Capacity	Customer delivery demands	Distance between customers
Experiment 1	Varied	60	10 to 30	5 to 25
Experiment 2	20	Varied	10 to 30	5 to 25
Experiment 3	20	60	Varied	5 to 25

The computation performance is evaluated in terms of the computing time the solver takes to solve the IP model to yield the global optimal solution. An embedded function in the LINGO optimization solver measures the total CPU time in solving the optimization model. It is shown under the elapsed runtime in the LINGO solver.

4.4.1 Experiment 1: Results and analysis for varying number of customer nodes

The number of customer nodes is varied while the maximum vehicle capacity, customer delivery demand and distances between customer nodes are kept constant. The input data for the different parameters are as follows:

- Maximum vehicle capacity – 60 units
- Customer delivery demand – 10 to 30 units
- Distance between customer – 5 to 25 km

A total of 18 test instances were generated for the computational experiment by setting the customer number from 10-20.

The result plotted in Figure 3 shows the changes in the elapsed time as the number of customer increases. Figure 3 shows an exponential increment in CPU time as the number of customers increases. The increase in customer number leads to the increase in the size of the problem and the complexity of the problem increases. Therefore, the logical processing time for CPU increases.

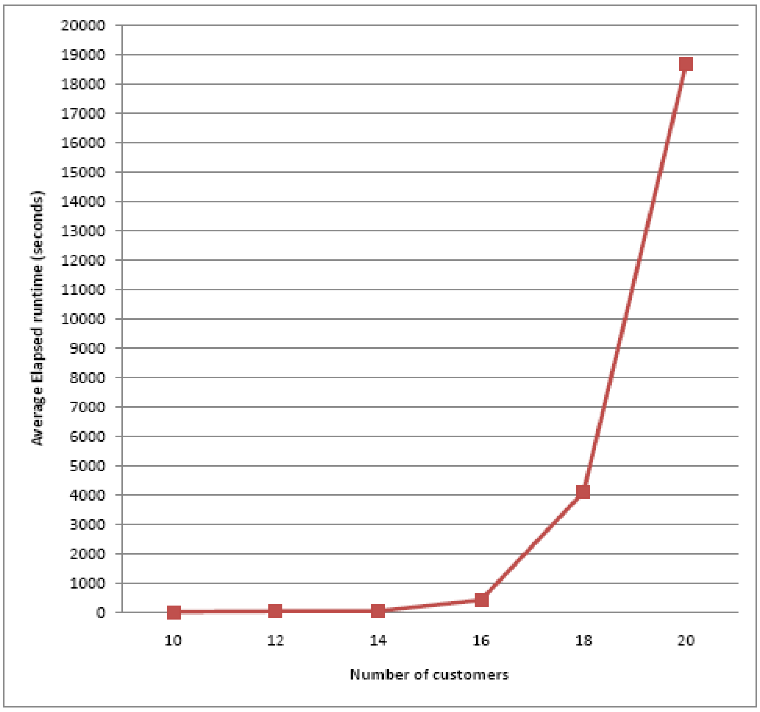

Figure 3: Graph of Elapsed runtime vs Number of customers

Thus, it can be realized that the number of customers is an important determinant of the duration of the computational time. The largest increase in CPU time occurs when the problem size increases from 18 to 20 customers. The runtime increases by more than 400%. It can be seen that CPU time becomes intolerably large for problems involving 20 customers and beyond. It seems that the model is not able to solve problems involving more than 20 customers within a reasonable time frame.

4.4.2 Experiment 2: Results and analysis for varying maximum vehicle capacity

The maximum vehicle capacity of the vehicle is varied while the other three parameters which are the Number of customer nodes, Demand of customers and Distance of customer nodes are kept constant. The inputs for the different parameters are as follows:

- Number of customers – 20
- Customer delivery demands – 10 to 30 units
- Distance between customers – 5 to 25 km

The model is tested with different vehicle capacities which ranged from 60 to 160. Figure 4 shows the changes in the elapsed time as the number of customer increases. The computational time exceeds 2 hours of CPU times for vehicle capacity of 60 and 80. For values from 100 to 125, the computational timings are well below 2 hours of CPU times. It can be seen from the graph that there were no more fluctuations of the CPU times for vehicle capacity above 120. Also, the graph exhibits a continuous decreasing trend as the graph slopes downwards.

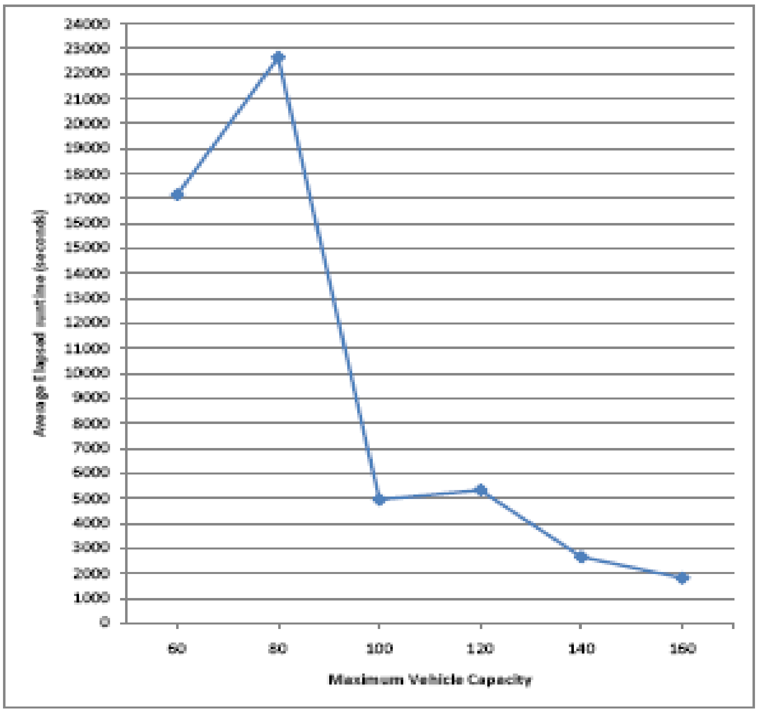

Figure 4: Graph of Elapsed runtime vs. Maximum Vehicle Capacity

Figure 4 shows that the CPU time generally decreases as the maximum capacity of the vehicle increases. Capacity constraint is less tight for test instances with larger capacities. Although it seems to suggest that increased capacity could be the reason for the decreased computational time, it does not absolutely guarantee a decrease with further increase in the capacity. . For instance, the run time for test instances with maximum vehicle capacity of 80 exhibits a higher value than 60. And it shows a slight increase when vehicle capacity of 120 is experimented. Such changes might have taken place because in some situations, the use of a specific vehicle capacity may permit greater number of combinations for certain customer demands range. Therefore, computation time becomes longer for the exact method to search for the optimal solution.

4.4.3 Experiment 3: Results and analysis for varying customer delivery demand

The results from Table 5 shows that the computation time needed for the route planning in the scenario of customer demands were to vary. This test was carried out because customer demands will change over periods of time. The computational times were consistently high for the first three series of demands. However, it is observed that the computation time plummets to near zero when experiment is done on test instance of demand (40 to 60). One likely reason could be that there were very few feasible combinations of routings which is tightly limited by the capacity constraint. Thus, the exact method searched for the best solution in a much shorter time frame.

Table 5: Results obtained by varying the Customer delivery demands

Customer delivery demand	Average elapsed runtime (seconds)
10 to 30	15668
10 to 40	13336
10 to 60	22754
40 to 60	5

In summary, it can be seen that the proposed IP model generally perform well for small customer size problems of 20 customers or less. Computational time becomes extremely high when the number of customers exceeds 20. Table 6 below summarizes the results and findings from experiment 1 to experiment 3.

Table 6. Summary of results analysis

	Number of customers	Maximum vehicle capacity	Customer delivery demands	Distance between customers	Trend of average elapsed runtime
Experiment 1	10 to 20	60	10 to 30	5 to 25	Exponential increase
Experiment 2	20	60 to 160	10 to 30	5 to 25	Decreasing
Experiment 3	20	60	0 - 60	5 to 25	Fluctuation

5. CONCLUSION

This paper proposed an integer programming (IP) model for CVRP. The IP model was applied to a case study involving delivery services. The optimum solution was obtained and the effect of key parameters e.g. number of customers on the computational performance of the exact method was studied. The number of customer locations, maximum vehicle capacity and customer delivery demand were varied and different sets of data were tested to evaluate the performance of the proposed model. It was found out that this approach is practical for small size problem of around 20 customers or lesser within a reasonable CPU time for solving.

There are many advantages in using exact methods in studying VRP. It is easier to understand and implement and it can also be scaled to suit the changing needs of the business in terms of the availability of transportation vehicles and variation in demand. The organization can routinely work for cost optimization with these kinds of methods. By enhancing route planning through the use of intelligent computational algorithms, companies can manage transportation cost effectively and make efficient use of the vehicles through e.g. making more truck load shipments. The method is tested for a Singapore case example, where transportation networks are well defined and the distance covered by delivery is not that long. Therefore, the model's application in places where the delivery points are further away and where the transportation network can be altered due to unavoidable circumstances, such as strikes and landslides, need to be tested with more complex problems. Such extension will help to develop a robust model suitable for most VRP cases.

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