DEVELOPING QUANTITATIVE ASSESSMENT METRICS FOR DETERMINING THE INTELLIGENCE LEVEL OF A HUMAN-COMPUTER INTERFACE

by

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Dedication

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Abstract

The quality of human-computer interfaces is becoming increasingly important as smart devices are becoming an essential part of our lives. Often what makes or breaks the market success of a device is not the hardware, but the quality and ease-of-use of the user interface of the smart device. Just as it is possible to discuss the intelligence level of machines in terms of their "machine intelligence quotient," it is becoming increasingly appropriate to discuss the "intelligence level" of a user interface. This new index would provide a quantitative assessment of user interface quality, and would be an indicator for rating the ease-of-use of the human-computer interface. In this study, a framework has been developed for the assessment of "user interface intelligence quotient" and is used to determine the quality of different smartphone interfaces. After conducting 200+ different human-smartphone experiments with popular smartphones and compiling the results using the methodologies developed, the results are compared to the actual opinion of the users. Results indicated that actual user opinions are in line with the calculated "intelligence" value of the smartphones. This study shows that there is a way to develop a "yardstick" to measure user satisfaction by using purely objective parameters.

Search Terms: Machine Intelligence Quotient (MIQ), User Intelligence Quotient (UIQ), Mobile, User Interface, Smartphones, Usability, Fuzzy Logic, Sugeno, Mamdani, FIS.

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Chapter 1: Introduction

1.1. Background

Man-machine interfaces, human-computer interfaces, and user interfaces are three different forms of interfaces between humans and computers which allow humans to interact with intelligent systems. Each of these interfaces has slightly different domains of specialization.

The term "man-machine interface" generally refers to the set-up of a control room in factories and may include the software interface of a computer as well as buttons, levers, controls to operate pumps, motors and indicators, and alarms in the control room. All this equipment together is the interface between the human operator and the complex plant operations [1, 2].

Human-computer interfaces have a more limited scope than man-machine interfaces and generally refer to the interaction between humans and the electronic messages generated by computers [3]. For instance, using a computer to access different programs and to complete certain tasks using the keyboard and mouse would be considered a human-computer interface, while a man sitting in a control room controlling a crane with buttons and levers would be considered a man-machine interface.

What is referred to as a "user interface" has an even more limited scope than the previous two definitions and generally refers to the interaction between the user and the software interface only [4]. It is the interface that has received the most attention in terms of scientific research due to its relevance to the mobile telephone market [5]. Man-machine and human-computer interfaces have also received attention regarding developing metrics for quality measurement, although not as much as user interfaces [6].

Measuring the quality of an interface requires the determination of many parameters which will be discussed in the coming sections. The references cited in [5, 6] indicate some of these important parameters.

The purpose of this research is to develop a new concept in line with the machine intelligence quotient (MIQ) [7] which describes the "intelligence level of user interface." MIQ may indicate the quality of a user interface, ease of learning, error proneness, and many other factors which may inherently define the quality of a user interface.

In the past few years, a very noticeable battle has begun in the smartphone industry. This battle gets tougher every year with more phones making their mark, as well as great technological advancements being introduced by each brand. Which phone is considered the winner of this battle depends on various factors, one of them being the user interface (UI). Hence, being able to develop a good UI and test it is a vital step in the success of the smartphone. This study offers a way to "measure" the smartness of a UI which would help to assure its success in the testing phase.

MIQ is an objective evaluation tool which measures the intelligence level of machines. It has proven to be a very useful tool since the concept of intelligence is difficult to describe even for human beings, let alone machines. MIQ, in its most widely accepted version, is defined as the extent to which a machine helps its human operator. The MIQ calculation has a mathematical framework which will be described in detail in the coming sections.

In this thesis, the idea of MIQ is adapted to the human-computer interface, and hence the concept of user interface intelligence is developed to describe the quality of human-computer interfaces.

As per our knowledge there has been no study that calculates the intelligence of a user interface; hence in this thesis the results have been obtained by using different methods and then compare these results to choose the best method of obtaining the intelligence of a user interface.

1.2. Literature Review

One of early papers that discusses the importance of user interface design is by Murphy [8]. He mentions that "when specifying a product, the user interface is often the most complex part of the customer requirements." This statement shows how important the user interface (UI) is in a product. He also mentions that the UI of a certain organization may lead to either its rise against its competitors, or its fall. Murphy gives so much importance to UI design that he goes so far as indicating that in a perfect world, the user interface would be designed solely by a human-computer interface professional. He discusses that there needs to be a continuous loop between engineering and marketing, where the marketing is in continuous contact with the consumer. Murphy states that "one of the reasons it is so hard to evaluate and refine the user interface is because it is so hard to measure"; this statement supports the importance of this project. Admittedly, he expresses his concerns regarding how one would know if a certain change would improve usability, and if it would actually be worth it.

Murphy then continues to discuss various techniques that can be adopted for ensuring that a UI is in fact what a user would expect. He mentions in his paper that feedback from users is one of the most important tests in order to determine if a UI has good usability. However, the method of conducting the tests is very important – for instance, the developer should not be present since the user might want to avoid offending the creator of the UI.

Reference [8] discusses the general idea of UIs and how essential they are. Various statements in the paper confirm that the measure of usability of an interface is very important and would prove to be very useful.

Various studies have used different methods for finding out how friendly a user interface is. One of the earliest studies was by Rauterberg [6] who developed his own technique for measuring and quantifying usability of man-machine interfaces. He came up with various terms, stated how they related to each other, and used them as his basis for identifying whether the user interface should be classified as good or bad. Two of the terms introduced by the author were "interactive directness" and "visual feedback." Using these terms, he differentiated between the three most common user interfaces: Command Language, which refers to command line-like interfaces; Menu Interface, which depends on menus and pop up dialogs; and Direct Manipulation, which is the well-known desktop-style user interface. The author then classified them as seen in Table 1.

Table 1. Final classification table developed by Rauterberg [6].

		Visual feedback	
		Low	**High**
Interactive Directness	**Low**	Batch	Menu Interface
	High	Command Language	Direct Manipulation

After establishing this representation, the author compared his results with those from previous empirical studies. When analyzing studies that compare Command Language interfaces with Menu interfaces, he found that there was no major difference between the two and neither proved greatly advantageous over the other. However, when examining studies that compared the Command Language interface with the Direct Manipulation interface, the latter showed greater advantage.

A study by Park et al. [5] reported how pleased users were with a touch user interface. The study targeted human emotion as the key for evaluating this user interface. In this study, an experiment was conducted where a sample of 30 students browsed through pictures on an iPod. The participants tested 18 different user interfaces that had the following motion parameters: acceleration rate, responding duration, and overshoot. After the use of a single interface, the user was asked to give feedback on the interface by filling out a questionnaire. This was repeated for all 18 interfaces with the 30 participants in random order. To connect between the users' emotion and the user interface, the authors developed a set of 11 bipolar affective attributes which were considered to be relevant to the touch user interface. The attributes, as well as the human emotion they relate to, are listed in Table 2 [5].

The *visceral level* refers to our physical senses and triggers the most immediate responses in comparison to the other levels. Following that is the *behavioral level* which is related to the behavioral aspects of a system. Last is the *reflective level* which consists of interpretations and reasoning influenced by different experiences and cultures.

Table 2. Affective qualities for touch user interface used by Park [5].

Level of emotion	Bipolar affective quality pairs	
Visceral	Heavy	Light
	Soft	Hard
	Tight	Loose
	Clicky	Smooth
	Precise	Imprecise
Behavioral	Simple	Complicated
	Clear	Ambiguous
	Deep	Shallow
Reflective	Natural	Artificial
	Refined	Unrefined
	Interesting	Dull

The results showed that the parameter with the strongest influence on emotions was the responding duration, while overshoot parameter was the weakest.

Moreover, the authors conducted a second similar experiment in the same study [5] to investigate users' emotional reaction to weight-of-force of the touch. This study was directed to touch user interface software designers so they could realize how different parameters of feedback from the software could garner different reactions from users.

Schmettow and Vietze [9] used the item response theory (IRT) to measure the usability inspection process. The usability inspection process is a critical process in which a program developer runs the interface under various tests to check for defects. The authors state that no generalized measurement of usability inspection processes has been introduced yet. All the measurement techniques have been either too specific, or lacking precision. The authors use the IRT to develop its simplest basic form, the Rasch model, which was tested and proved to be successful. Nevertheless, it can only be used to measure the inspection process of usability and not how intelligent the user interface is.

In another study [10] the authors addressed some of the difficulties that usability specialists face when trying to determine whether an interface is user-friendly. In their study they responded to the difficulties with existing usability engineering tools, and noted down each problem that the specialists faced as a usability problem (UP). Later the researchers were able to list the tools available for overcoming each UP and performed a study to evaluate these solutions [10]. However, again the study did not provide any means of quantifying or measuring the intelligence of the user interface.

Haiyan and Baozhu dedicated their research [11] to using a new data-processing mechanism for testing the usability of mobile devices. Their data-processing mechanism consisted of three main areas, *data collection*, *analysis,* and *suggestions* from users. In the data collection stage, the authors collected the data from the different phases of the experiment and listed the data collected from each phase and the means of collecting it. A sample of this data can be seen in Table 3.

After collecting the data the authors start the analysis stage. This stage is divided into three parts. The first part is the case where they collected data about the scenario and the questionnaire results before the scenario. Then the second part concentrates on analysis of each task completion rate, duration, mistakes and so on. Finally the operation which summarizes the analysis for reviewing. Finally the study [11] proposes that this systematic method be used for usability testing since it increases efficiency of usability testing. However, the authors did not work on how to measure or perform usability testing for mobile phones instead they have proposed a new way of organization of data to better understand how to perform the measuring of the usability.

Table 3. Usability Testing, Data Collection Stage [11].

No.	Phase	User behavior and evaluation	Collection method	Data
1.1	Operation phase	User operation (mean)	- Video capture device to record -Software recording -Observer observed and recorded	-Mouse trajectory -Mouse events -Keyboard events
1.2	Operation phase	User operation (flow)		-Operation flow (sequence) -Operation flow (quantity)
2	Operation phase	Countenance		Countenance during user operation, including confusion, anger and so on
3	Survey before	Comments	-Observer listening to records	Subjective comments
4	Survey after	Comments	-User completes the survey	Questionnaire

Yu and Liu [12] proposed a way to improve the performance and usability of mobile computers by adding audio information in the menus. In order to compare the mobile computers' menus' usability there had to be usability tests conducted on the interfaces before and after adding the audio support. As a means of comparing the usability of both interfaces, the authors used the System Usability Scale (SUS). The SUS is a fixed questionnaire that was initially designed by John Brooke in 1986 [13]. The authors modified the questionnaire slightly and used the replies to the questionnaire as a means of comparing the two interfaces. The SUS for this study proved to be useful since its subjective responses would serve well for a comparison of two interfaces. However, the SUS would be difficult to use as a standalone metric for measuring the usability of an interface.

There were two studies that addressed the issue of conducting usability tests in laboratories versus field studies [14, 15]. Authors of study [14] used questionnaires before and after conducting the tests in order to get an idea of the usability of the devices being used indoors and outdoors. The results showed that field testing caused the users to find out more of the usability errors than laboratory testing. The authors of [15] however had a different case. They tested the usability of a children's painting application and a game (both PC-based) but the field test was conducted for children in a preschool whereas and the lab testing was done with children in the authors' lab. Since the authors were testing usability with children they could not rely on questionnaires for assessing the usability. Hence they recorded all the children's experiences and noticed their facial expressions as well as their ability to complete certain tasks. They noticed that it was harder to conduct the study in the children's preschool due to disturbances from other children as well as the unavailability of all their required tools and the difficulty of using the available ones which they were not familiar with. However, field testing had the children conduct exercises in a more familiar setting and so they were more relaxed.

It was concluded that field testing is more favorable than laboratory testing; however, the difficulties of conducting field testing increase vastly compared to laboratory testing. A study by Liang et al. [16] addressed these difficulties and successfully conducted a remote usability test for mobile phones. Instead of having the users placed in a lab, they were asked to use the mobile phones in certain rooms that contained cameras and other recording devices. Figure 1 shows the difference between the two settings discussed by [16]. The authors also added software on the mobile devices (only Android phones where supported) that would send screenshots over Wi-Fi with every change that the user made on the device. This would make it possible for the user to be a bit freer while moving around and using the mobile device. The authors then played the images of the screenshots one after the other in real time to show how long the user took to complete certain tasks. The authors however did not measure usability but only introduced a new method for conducting usability testing. Their method was successful, however, limited to powerful smartphones running an Android operating system.

Finally, an important study by Schusteritsch et al. from Google [17] showed the different options for conducting usability testing on mobile phones. Since it is important to take note of the users' experience with the mobile phone during testing, there should be observation tools set up in the most convenient way possible.

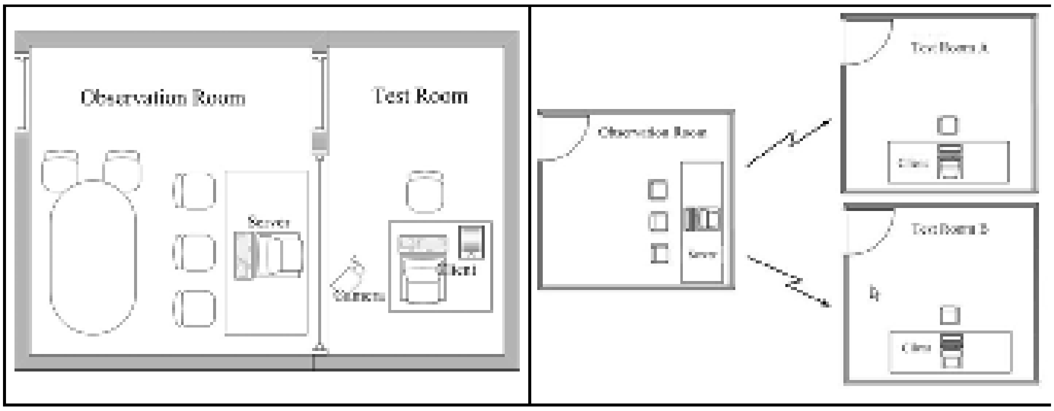

Figure 1. The figure on the left shows a laboratory setting and the one on the right shows a remote setting [16].

The authors described various ways for conducting usability tests on mobile phones starting with “direct observation.” In this method, the observer(s) stand by the user and directly take note of the usage of the mobile phone. This method would be uncomfortable for a large number of observers and also no record of the experiment is kept for future reference. The second method is “document camera on desk.” In this method the mobile phone would be fixed to the desk with a document camera pointing at it to record the experiment. Nevertheless, this gives the user very restricted movement and uncomfortable usage of the phone. The third method is a sled-based observation system. In this method the mobile is fixed on a sled with two cameras mounted on it. This gives free movement of the phone while recording the activity on its screen and keypad. However, the authors noticed that it becomes bulky and heavy for the users to hold for a long time. Finally, the authors came up with the fourth method which is “camera directly mounted on phone” in which the cameras are attached to the phone making it lighter and easier to use.

After conducting this detailed research there were various ideas that were taken from the experience of previous authors. In this thesis the experiments were conducted in the field, since they were conducted in a university where most of the participants studied. It was believed that this would feel more relaxed and not as frustrating for students compared to bringing them into an unfamiliar lab where they would feel uncomfortable.

Keeping note of the different methods discussed by Schusteritsch et al. [17], this thesis uses ideas from them in order to conduct the experiments. Using a high definition camera on a tripod fixed behind the user directed at the smartphone gives the user freedom to move while the experiment is recorded. In addition, an observer would be standing alongside the camera to take notes as well as ensure the smooth continuation of the experiment.

1.3. Research Methods and Materials

This thesis is based on the MIQ method that was produced by Bien [7], Bien et al. [18] and Kim and Kim [19]. MIQ is a concept that has been used to successfully measure how smart a machine is. This method compares how much work the machine does compared to the human controller. The more work the machine does, the less the human controller has to do which is what shows that the machine is smart. In this study, the MIQ concept was translated to be able to calculate the intelligence level of user interfaces in mobile phones rather than of machines.

Since this thesis is targeting the measurement of user interfaces, it is a good idea to use fuzzy logic as another means of measuring them. User interfaces before have always been described as good, bad, and excellent. Fuzzy logic deals with the translation of these words into numbers that we can measure.

In this thesis, two methods are used to calculate the intelligence of the user interface of different smartphones. These two methods are using the MIQ method and fuzzy logic. After getting results from the two methods, these results are compared with the results from the questionnaire that the users replied to. Finally the two methods will be compared.

This thesis introduces a new metric for calculating the intelligence level of a smartphone user interface. This will be called the User Interface Intelligence Quotient (UIQ). The results obtained prove the usefulness of this metric as it calculates the UIQ accurately. This is determined by comparing the results of the new metric with the results from a survey taken by smartphone users.

1.4. Thesis Organization

The remainder of this thesis is organized as follows: Chapter 2 talks more about MIQ and fuzzy logic; Chapter 3 discusses the experiment conducted to build up sample data for the testing and the use of the framework; Chapter 4 discusses the application of the MIQ metric and fuzzy logic to calculate the UIQ; Chapter 5 shows the detailed calculations completed; and Chapter 6 reviews the results and concludes the study.

Chapter 2: Determining Intelligence of Smart Systems

2.1. Machine Intelligence Quotient (MIQ)

The Machine Intelligence Quotient, MIQ, is a metric used for measuring the intelligence of automated systems. It was initially defined by Bien [7], Bien et al. [18] and Kim and Kim [19] and then other researchers came along to build on this concept. Some of the research studies measured the intelligence level of a variety of systems, from nuclear power plants [20, 21] to distributed network system setup [22]. Finally, Ozkul [23] presented a more detailed process of successfully calculating the MIQ of a robot before and after it was given a visual unit. His research is discussed in further detail in this section.

2.1.1. Measuring intelligence level of Human-Machine Cooperative Systems

In reference [23], the author firstly describes that an intelligent system includes three elements in general, and these are:

- Human operator
- Intelligent machine
- Non-intelligent component

The basic idea of a human-machine cooperative system is a setup which is controlled by a human-operator. The intelligent part and the non-intelligent part of the setup are there for completing a task. The non-intelligent part of the system is there for processing or generating something. As in the case of a power plant this may be the power generation equipment.

The intelligent part, on the other hand, aids the human operator to complete his task. In most cases intelligent part is a computer program that runs the plant, in other words, operating or regulating the plant so that it works and generates the desired output. As in the case of a power plant, the computer system operates and regulates the machinery so that the power plant continues generating steady power output.

Ultimately, a human operator controls the whole system. The computer helps the human operator to complete his task. As computer aids the human operator more and more toward his task, it will be considered more and more "intelligent."

The human operator is the area of the system that is entirely controlled by a human where he is able to give commands and order the intelligent machine using devices such as levers, buttons, and so on. The intelligent machine in turn takes in the commands and interprets them to be able to control the different parts of the non-intelligent components such as the conveyor belt, pistons, and so on.

2.1.2. Example of MIQ

In order to better understand the MIQ concept, Ozkul [23] presented in his study an example of how adding a visual unit to a robot in a plant would increase its intelligence, MIQ.

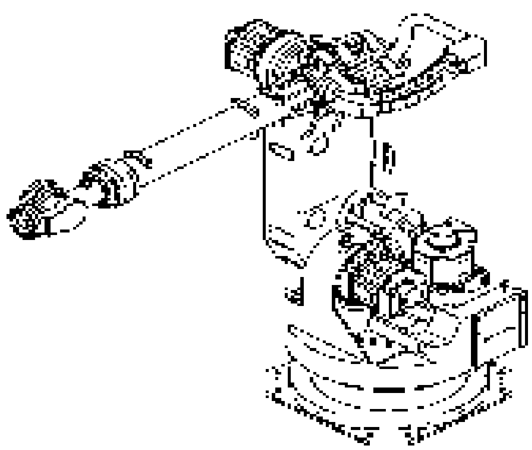

Figure 2. Robot in a plant [23].

Figure 2 shows a robot in a plant which adds components to a board that is placed in place by the human operator. The cumulative intelligence quotient (CIQ) required for this task is 49. At this current state the human intelligence quotient (HIQ) required is 16. Hence, according to the MIQ concept, the machine intelligence quotient of the robot is calculates as:

$$MIQ = CIQ - HIQ = 49 - 16 = \mathbf{33}$$

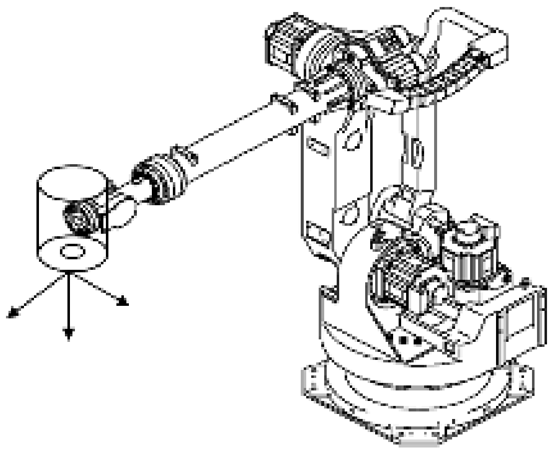

Figure 3. Robot in plant after addition of visual component [23].

Now consider Figure 3 which shows the robot with an added visual component. In this case the human operator is not required to set up the board in exact location since the robot can direct itself to the board. This causes a decrease in the required human intelligence quotient, and it becomes 10, whereas the complete intelligence quotient remains constant since the task to be completed has not changed. Hence, after the addition of the visual component to the robot its intelligence quotient is now calculated as:

MIQ = CIQ – HIQ = 49 – 10 = **39**

The above example shows that the addition of a visual component increased the intelligence of the machine. This is because it reduced the work load on the human operator.

2.2. User Interface Intelligence Quotient (UIQ)

We have adapted a similar philosophy and methodology for defining user intelligence quotient. User intelligence quotient is a unitless indicator that shows the relative intelligence of comparable systems.

The basic philosophy of determining the intelligence level of a smart system is as follows. A smart system is there to help a human operator to accomplish a task. Accomplishment of the task is the sole responsibility of the human operator. Machines do not really possess any intelligence themselves but are there to help the human operator to accomplish the task. Accomplishment of a task requires a certain amount of effort and intelligence from the human operator. We call this “CIQ” which stands for Complete Intelligence Quotient for accomplishing a certain task. As in the case of smart phone systems, this may be an operation of sending an SMS to a person or entering a website using the smart phone. The human operator has to spend a certain amount of effort for accomplishing this task. The amount of human effort required toward accomplishment of this task is called “HIQ” which stands for Human Intelligence Quotient. If the human operator were to complete this task on his own without any help from any smart gadget, we would say:

CIQ = HIQ

Now if we consider the existence of a smart gadget to help the human operator, then the equation would be as follows:

CIQ = HIQ + UIQ

Now in this equation, UIQ is the intelligence quotient of the smart gadget helping the human operator. The smart gadget helps the human operator to accomplish his task. If the smart gadget is helpful in doing this we consider that the work done by the human operator becomes less (HIQ decreases and UIQ increases). When comparing the intelligence level of two different smart gadgets, we look into the level of help they provide to the human operator. The one that helps the human operator more by reducing his task (decreasing HIQ) is considered to be the one with the higher UIQ.

In summary, the amount of intelligence required for accomplishment of a specific task is constant. The smart gadget that helps its operator to accomplish this task with the least effort is considered to have a higher UIQ than the other smart gadgets. The UIQ value is a relative index which indicates the level of smartness of two or more smart gadgets; the higher the value, the higher the intelligence.

As in the case of sending an SMS to a person, if the task can be done easier, with less effort on a specific operating system, the corresponding operating system will be considered to have a higher UIQ.

The following sections describe the process of determining the CIQ, HIQ, and UIQ of user interfaces.

2.2.1. Intelligence Task Graph

The MIQ of an intelligent machine is defined by the extent to which it can help the human operator in completing a required intelligent task. This task can be represented by a task graph which is a state diagram that displays various small tasks required to complete the whole task. The state diagram, seen in Figure 4, consists of circles that represent the task and its complexity, and arrows that represent the flow from one task to another. The diagram also shows the tasks that are completed by the human controller and those that are completed by the intelligent machine.

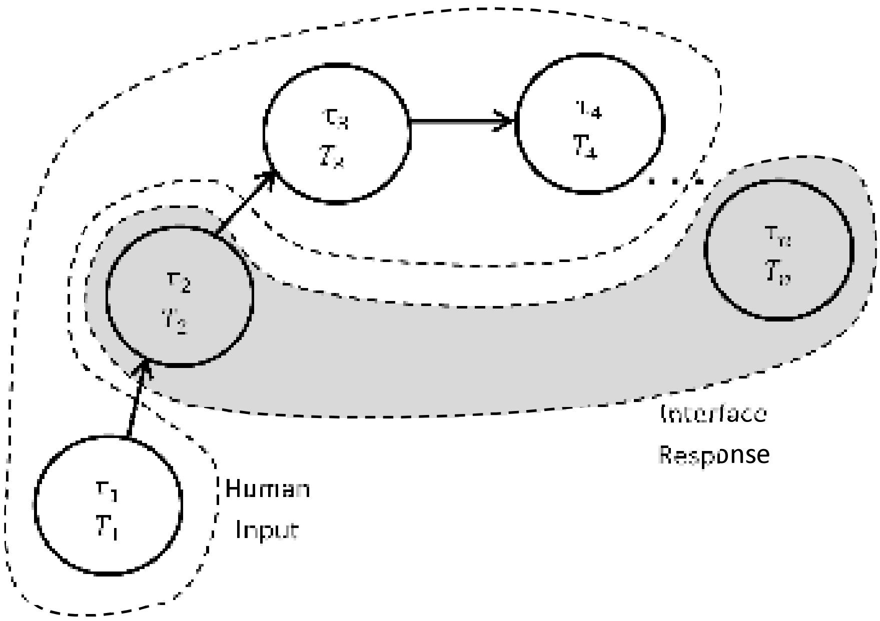

Figure 4. Intelligence Task Graph.

An intelligent task is made up of various smaller tasks, called subtasks, which are represented in a set called **T** [20]:

$$\mathrm{T} = \{T_1,\ T_2,\ T_3 \ldots T_n\} \tag{1}$$

Each subtask may have a different complexity, represented by **τ** [20]:

$$\tau = \{\tau_1,\ \tau_2,\ \tau_3 \ldots \tau_n\} \tag{2}$$

Equations (1) and (2) show the set of subtasks and their complexities. Two more variables introduced by the author for the calculation of the UIQ were: Data Transfer Matrix **F**, which represents the amount of data transferred from one subtask to all the other subtasks during the completion of the main task; and Task Allocation Matrix A, which indicates whether the human or interface was assigned each subtask. The representation of these two matrices is seen below in Equations (3) and (4) [20]:

$$F = \begin{bmatrix} 0 & f_{12} & f_{13} & f_{14} & \cdots & f_{1j} \\ f_{21} & 0 & f_{22} & f_{23} & \cdots & f_{2j} \\ f_{31} & f_{32} & 0 & f_{33} & \cdots & f_{3j} \\ f_{41} & f_{42} & f_{43} & 0 & \cdots & f_{4j} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ f_{i1} & f_{i2} & f_{i3} & f_{i4} & \cdots & 0 \end{bmatrix} \quad (3)$$

Where f_{ij} represents the amount of data being transferred from T_i to T_j.

$$A = \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \\ a_{41} & a_{42} & a_{43} \\ \cdots & \cdots & \cdots \\ a_{n1} & a_{n2} & a_{n3} \end{bmatrix} \quad (4)$$

Where column 1 represents tasks completed by the intelligent machine, column 2 represents tasks completed by the human operator, and column 3 represents the tasks completed by the non-intelligent machine component.

2.2.2. Control Intelligence Quotient and Human Intelligence Quotient

Using these variables, the author was then able to calculate what is known as the Complete Intelligence Quotient (CIQ) and the Human Intelligence Quotient (HIQ). The author [20] defines formulas for these new variables as:

$$\text{CIQ} = \sum_{i=1}^{n} a_{i1}.\tau_i + \sum_{i=1}^{n} a_{i2}.\tau_i \quad (5)$$

$$\text{HIQ} = \sum_{i=1}^{n} a_{i2}.\tau_i + Cmh \sum_{i=1}^{n} \sum_{j=1}^{n} a_{i1}.a_{j2}.f_{ij} + Chm_i = 1ni = 1na_{i2}.a_{j1}.f_{ij} \quad (6)$$

Where *Cmh* and *Chm* are interface complexity values that define the difficulty of transferring the data from machine-to-human and from human-to-machine, respectively. The author mentions that these variables indicate the difficulty of entering or interpreting data, that they vary from 0 to 1, and that their value for a well-designed system would be approximately 0.05.

2.2.3. User Interface Intelligence Quotient (UIQ)

UIQ is the contribution of the intelligent smart machine alone to complete a certain task. Unlike CIQ, which is the total effort by human and machine in completing the task, HIQ is the effort by the human alone for completing the task. Hence the following equation describes the relationship which is a modification of the MIQ equation from [20]:

$$\text{UIQ} = \text{CIQ} - \text{HIQ} \quad (7)$$

2.3. Fuzzy Logic

We can use Fuzzy logic as a way of designing intelligent systems. Intelligent systems, which are extremely difficult to design using classical methods, can be designed with fuzzy logic methodology fairly easily. Fuzzy logic provides a way of mimicking decision behavior of a human expert with a series of if-then rules. In the context of this research, fuzzy logic will be used for determining the intelligence level of smart systems. An alternative system using a fuzzy logic decision mechanism will be developed which will be used for determining the intelligence level of smart systems. A brief description of fuzzy logic systems is provided below.

Fuzzy logic deals more with words than numbers. Over the years it proved useful in various fields, starting from the early 1970s where fuzzy logic was used for recognition of handwritten numeral characters [24] until recent years where it was used for measuring risk analysis in cancer disease [25]. Sometimes words are more useful and meaningful than having exact numbers, as they can make it more understandable by users, and make it closer to our everyday encounters [26]. Consider Figure 5, which shows the difference between precision and significance in the real world.

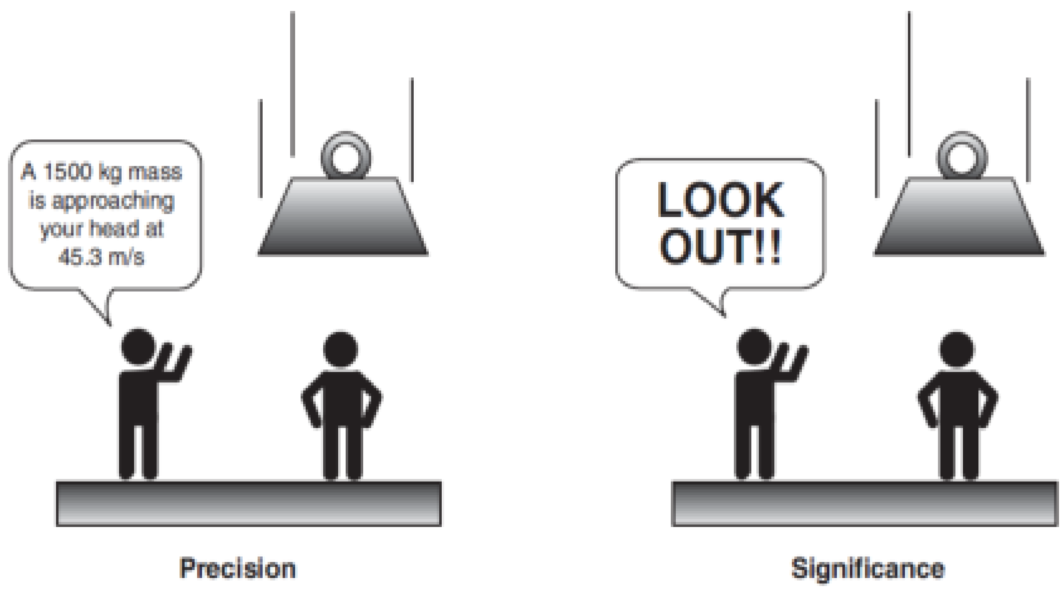

Figure 5. Precision vs. Significance in the Real World [26].

2.3.1. Fuzzy Set Theory

Fuzzy logic is based on the idea of fuzzy set theory which was proposed by Lotfi Zadeh in 1965. Fuzzy set theory introduces the idea that in real life not everything can be represented in classical crisp sets (Figure 6). Sometimes a member of a set could belong to it only with a certain degree, and at the same time not belong to it (Figure 7).

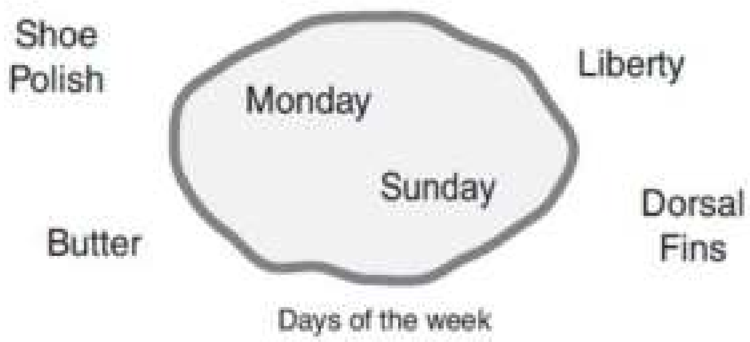

Figure 6. Crisp set example: Days of the week [26].

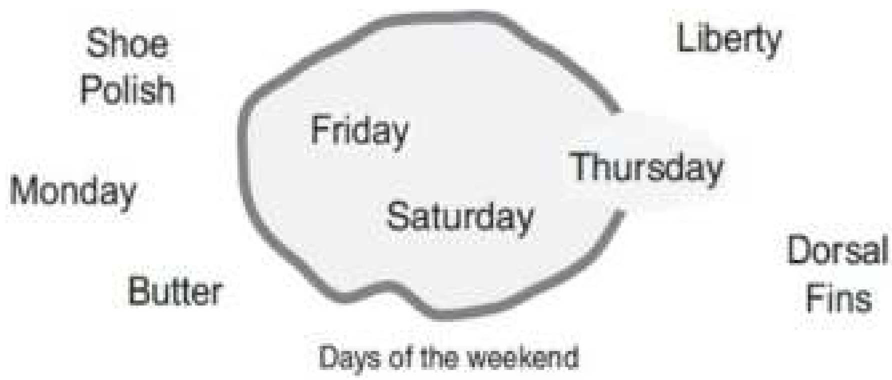

Figure 7. Fuzzy set example: Days of the weekend [26].

The introduction of the idea of fuzzy sets meant that we could now answer yes-no questions with a not-so-yes-or-no answer. Referring to the examples presented in Figures 6 and 7, we can say that Friday and Saturday are definitely a "yes" answer, or a Logic 1, to the question "Are they a weekend?" But what about Thursday, is it considered a weekend or not? Here is where fuzzy logic makes it easy. Instead of having to answer it with either a yes or no (1 or 0 in logic) we can answer it with a degree, a non-definite answer. Thus, instead of giving it a 1 or 0, we can perhaps give it a 0.6. This number can be considered as a membership value, a value that corresponds to how much Thursday is considered to be a member of the weekend set.

2.3.2. Membership Values and Membership Functions

Now if we consider the idea of membership values, we can develop functions that represent these values. These functions are known as membership functions, and they can be represented in different types of graphs depending on the system we are considering. Figure 8 shows the difference between having membership functions for the crisp sets and for the fuzzy sets. Since these graphs are continuous, it is now easy to trace any time of day back to the weekend set. No matter what time of day is asked, we can give it a degree (value) in the set.

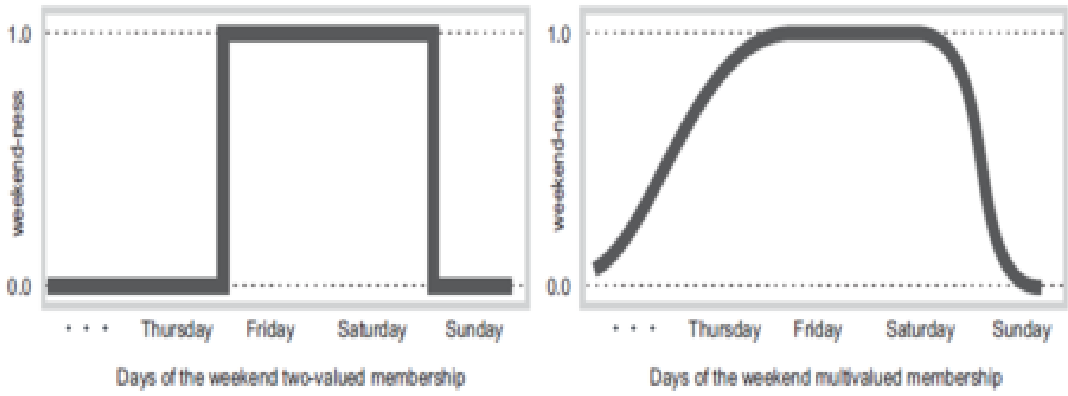

Figure 8. Membership functions comparison [26].

In Figure 6, the x-axis represents the time of day and the y-axis represents the membership value with which the corresponding time belongs in the weekend set. As seen in the crisp set graph (left) as soon as it reaches midnight of Thursday the graph jumps to a membership value of 1, whereas in the fuzzy set membership function (right) the membership values increase smoothly as the day progresses. This is how we humans experience a Thursday in real life: as the day goes by, we feel more like it's a weekend.

2.3.3. Fuzzy Interface System

In order to evaluate a problem with various inputs and outputs, a Fuzzy Interface System (FIS) needs to be developed. This FIS would contain various inputs and outputs which in turn contain various membership functions. To obtain the required output from the inputs, multiple if-then rules would be applied on the various membership functions.

There are two types of Fuzzy Interface Systems available: Madmani and Sugeno. Various studies have been dedicated to comparing the two systems in different systems [27, 28, 29]. However, the studies each found that each type of FIS proved to be suitable for different systems, so there is no way to choose one as always the best way to go. MathWorks has listed the advantages of the two types of FIS as the following [30]:

Advantages of the Sugeno Method

- It is computationally efficient.
- It works well with linear techniques (e.g., PID control).
- It works well with optimization and adaptive techniques.
- It has guaranteed continuity of the output surface.
- It is well-suited to mathematical analysis.

Advantages of the Mamdani Method

- It is intuitive.
- It has widespread acceptance.
- It is well-suited to human input.

2.3.4. How will fuzzy logic be used for determination of UIQ

A Fuzzy logic system will be used to determine UIQ in a different way. The fundamental definition of UIQ will be exactly the same. But instead of using a fixed formula for determining the UIQ value, the fuzzy logic system will use a series of if-then rules for determining UIQ. The fuzzy logic system will be using exactly the same values generated through experimentation, but when it comes to determining UIQ, we will be using the methodology of an expert human. The exact rules of the fuzzy logic system will be given in the coming sections.

Chapter 3: Determination of User Interface Intelligence

3.1. Concept of User Interface Intelligence

Just as the Machine Intelligence Quotient is used for describing intelligence level of machines, we can talk about the intelligence level of user interfaces. A user interface is the interface between the human operator and the computer hardware which ultimately helps the human operator to communicate his orders to the computer hardware. In the case of a smartphone, the computer hardware is the phone gadget which calls the dialed number, sends the SMS message, or goes into the web page demanded by the human operator. Ultimately the human operator gives the orders and the user interface helps the human operator communicate the orders to the phone gadget. A user interface can be considered more and more intelligent if it is making the human operator's job easier and easier.

In today's smartphones, the user interface, together with the operating system, is an integral part of the phone gadget. When we rate a phone as "intelligent" or a "dumb," we are actually rating the quality and intelligence level of the user interface. When a human operator finds a smartphone is "easy" to use and accomplishes the task easily, we consider that smart phone "highly intelligent." Just as in the case of a machine intelligence, the more helpful the operating system, the more intelligent the user interface.

To measure the intelligence level of various operating systems available on the market, we have designed an experiment to measure the "level of help" provided by each operating system. The experiment is intended to determine the intelligence level of the different operating systems as objectively as possible while a human operator is trying to accomplish a task with a phone gadget.

The data obtained through the experiment is processed according to a model that will be explained in the coming sections.

3.2. Experiment Details

Our experiment is designed to observe and measure how human users interact with the user interface of smartphones. Users are observed and several parameters are recorded while they are interacting with the user interface. The experiment developed for this study was conducted on the American University of Sharjah campus, in the computer engineering graduate students' office. A total of 10 participants volunteered for this experiment with ages ranging from 19 to 27. Six of these participants were male while the other four were female. The maximum educational level of the members was a Bachelor's Degree. The names of the phones and their makers will not be listed for privacy purposes; hence in this study they will be named as OS1, OS2, OS3, OS4, and OS5. The participants were given IDs as A, B, C, and so on up to J.

The experiment was divided into three parts. In the first part, the volunteers were asked to complete certain functions on five different smartphones, picking them in a random order. The second part required the same participants to complete the lock and unlock task. The final part of the experiment was a survey filled out by the participants. They were asked to rate the difficulty of completing the different functions on each smartphone.

3.3. Experiment Scenario

Each of the participants individually entered a room and was asked to be seated at a desk. He/she was then presented with a form which described the experiments to be conducted as well as the various steps he/she would be required to complete. After reading the form carefully, the participant was asked to sign it and was notified that the whole experiment would be recorded. A copy of the form is included in Appendix A.

3.4. Experiment 1: Complete the Tasks

In this part of the experiment the participants were asked to complete four different tasks on the five smartphones:

1. Call a certain number.
2. Send a message containing a fixed text.
3. Set an appointment in the calendar.
4. Go to a webpage.

The participants started the experiment by picking up a smartphone in a random order, completing all the listed tasks, and moving on to the next phone. Since the whole experiment was recorded, it was possible to go through all the videos later and precisely measure how long it took to complete each of the tasks.

The time taken for the completion of each task was recorded in a table, with the average time noted for further calculations. A sample of the table is shown in Table 4 for the task of "make a call" on OS2.

Table 4. Sample of results for subtasks of the make a call task on OS2.

OS2	**Time spent on task by each user (seconds)**										**Avg**
Make a Call	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	
Locate Phone Application	3	1	3	0	5	6	3	3	6	6	3.6
Response from Phone	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.01
Dial Numbers	9	6	11	6	6	8	10	11	13	12	9.2
Click Call	0	0	1	0	0	0	1	1	1	2	0.6
Response from Phone	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97

3.5. Experiment 2: Complete the Lock-Unlock Task

After completing the first part, the participants were asked to move on to the second part. This task required them to lock and unlock each smartphone as many times as possible in 30 seconds. Locking and unlocking the screen is considered a simple task. How many times a user can do this in a fixed amount of time gives an indication of how much dexterity is required for completing the task. A supervisor would keep track of the time while the participants concentrated on completing the task. When the time was over for each phone, the supervisor would signal the participant to stop and move on to the next phone. Again, the experiment was recorded and hence it was easy to count exactly how many times it was possible to complete the task on each phone. The numbers were recorded again in a table and a total was calculated for each phone. These numbers would later be used for further calculations. Table 5 shows the final results for lock and unlock task executed for all the smartphone operating systems.

Table 5. Total number of locks and unlocks per phone.

Phone	No of times by Subject No:										Total Per Phone
	A	B	C	D	E	F	G	H	I	J	
OS1	8	9	6	9	8	6	8	8	7	8	77
OS2	17	14	11	17	18	9	17	12	10	10	135
OS3	16	9	9	12	14	7	12	9	8	9	105
OS4	17	15	15	15	19	12	18	13	10	13	147
OS5	23	18	16	17	17	14	18	19	12	16	170

3.6. Experiment 3: Complete the Survey

Finally, the participants were asked to fill out a survey regarding their experience with the smartphones. A sample of the survey can be seen in Table 6. The participants filled in all the fields and the data was collected in a table for further analysis.

Table 6. Sample for survey to be filled.

Step	Easy	Medium	Difficult	Complex
1. Unlock phone				
2. Go to Phone application				
3. Enter the numbers				
4. Call				

Table 7 shows a sample of the final table for calculation of the replies given by the participants for the "make a call" function on OS2. The numbers were filled in the table as follows:

- Easy = 1
- Medium = 2
- Difficult = 3
- Complex = 4

Table 7. Survey results for the "make a call" function on OS2.

OS2	A	B	C	D	E	F	G	H	I	J	Sum 1	Sum 2
Go to Phone	1	2	1	1	1	1	3	1	1	1	13	34
Enter Numbers	1	1	1	1	1	1	1	1	1	2	11	
Call	1	1	1	1	1	1	1	1	1	1	10	

Chapter 4: Applying Suggested Methods to the Collected Data

4.1. UIQ Metric

4.1.1. Building the Task Graphs

In order to be able to calculate the UIQ for the tasks for the different phones, a task graph was drawn for each phone. To build the task graph, each function was split into various small tasks and each of these tasks was assigned to either the human controller or the user interface. All the task graphs developed for the “go to webpage” task are seen in Figures 9-13. The task graphs for all the tasks can be seen in Appendix B.

Below are the task graphs for the “go to webpage” function for all the smartphone operating systems. The task number in the task graph is shown by a circle that contains **T_i** where **i** is the number of the task in the function and a number which shows the complexity of the task. If the task is performed by the internal part of the user interface and the complexity is unknown, the complexity will be displayed as UI.

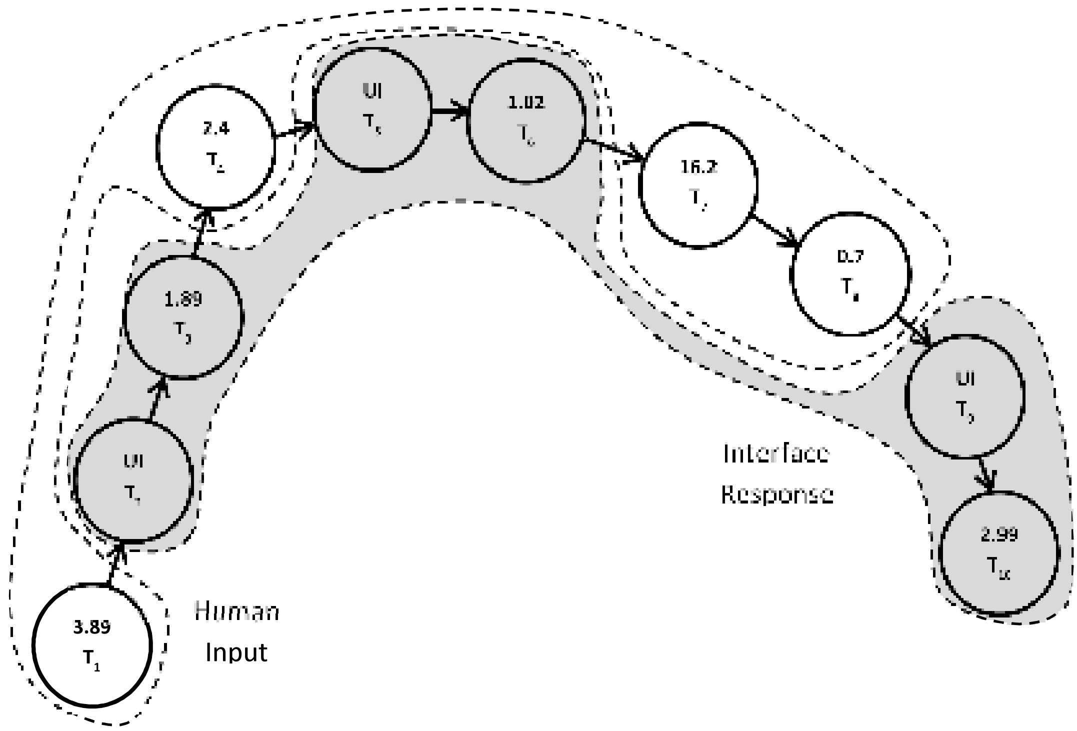

Figure 9. Task Graph for “Go to Webpage” Function on OS1.

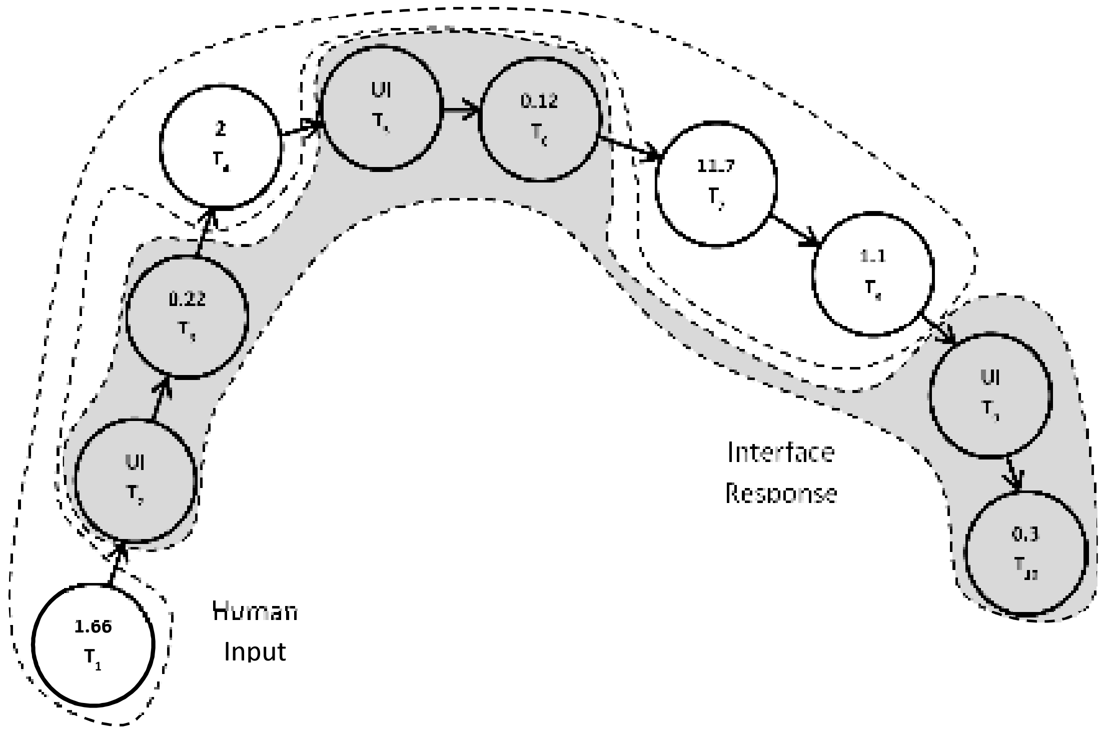

Figure 10. Task Graph for "Go to Webpage" Function on OS3.

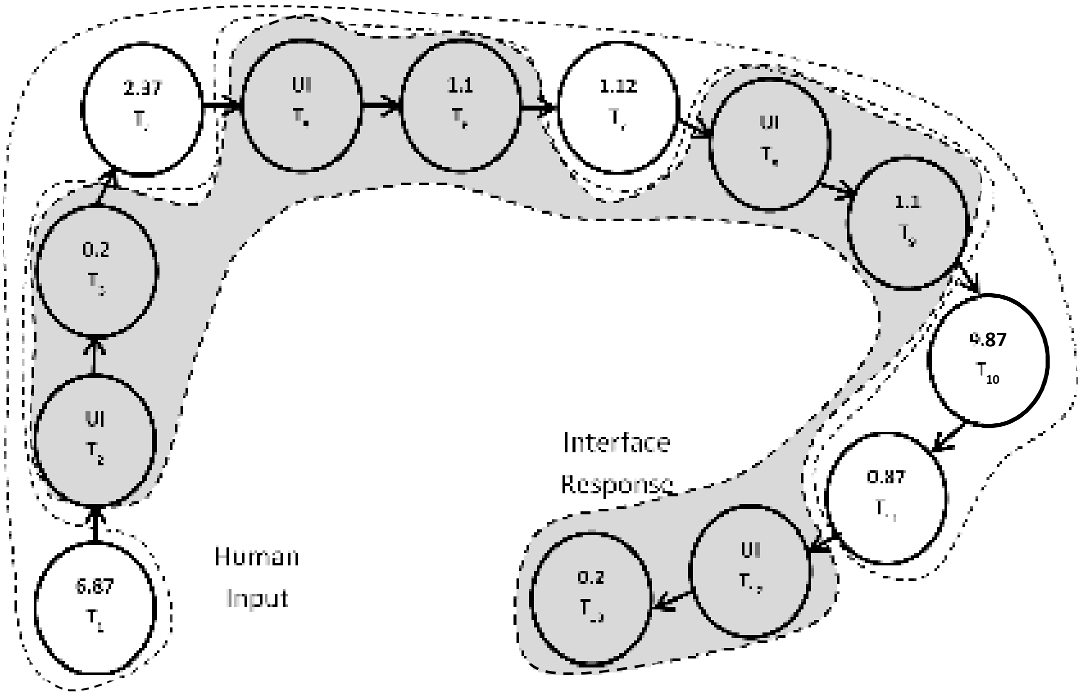

Figure 11. Task Graph for "Go to Webpage" Function on OS2.

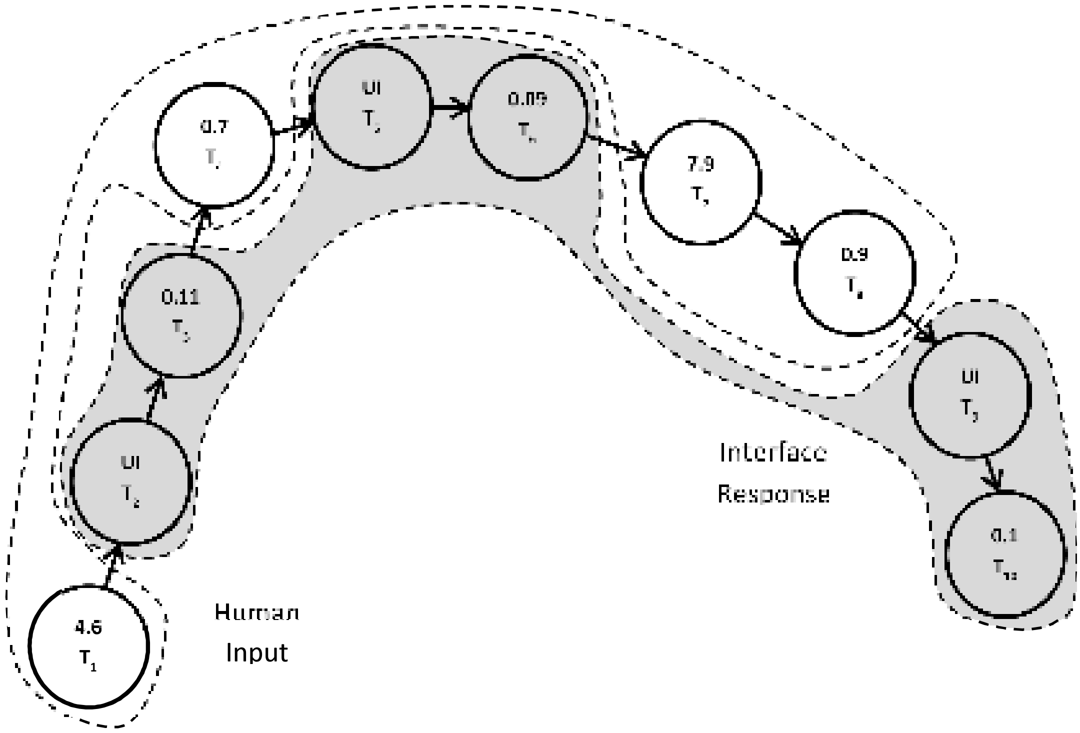

Figure 12. Task Graph for "Go to Webpage" Function on OS4.

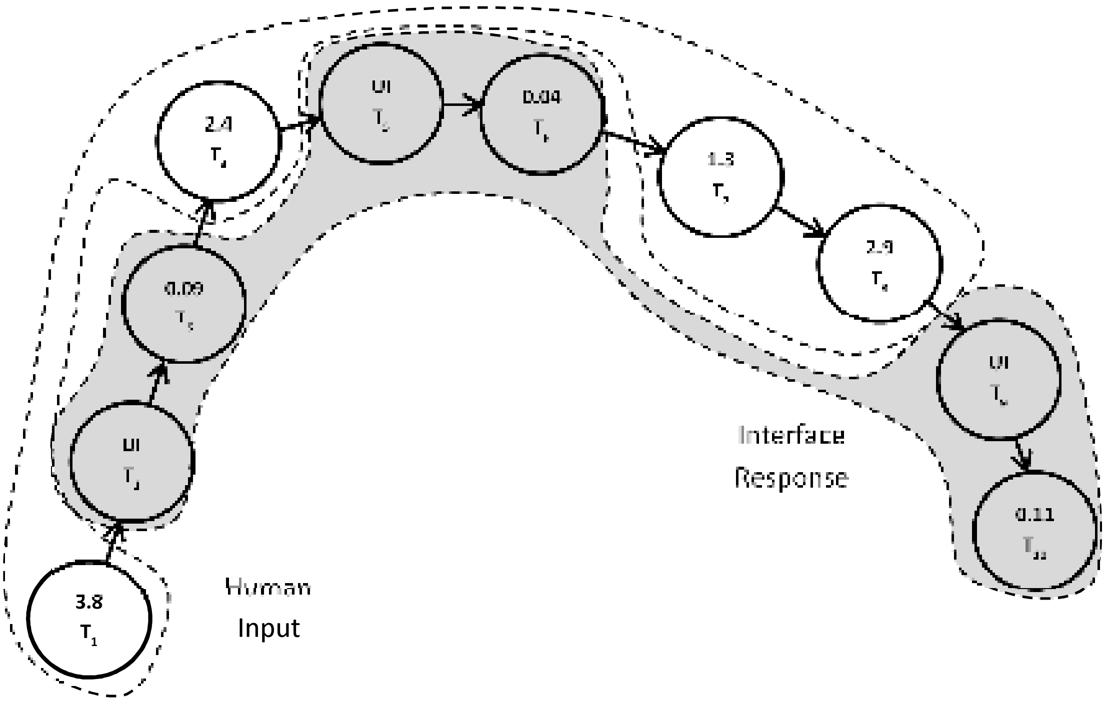

Figure 13. Task Graph for "Go to Webpage" Function on OS5.

4.1.2. Applying the UIQ Metric

4.1.2.1. Calculating CIQ and HIQ

Each of the functions completed is represented by a task graph, which shows the various tasks required to complete a function labeled by their complexities. The complexity of each task (τ) is represented by the time taken to complete that task since time and complexity are proportional to each other. Table 8 shows the "make a call" function, its tasks, and the complexities of each task which are calculated as the average time taken to complete the task by all the participants.

Table 8. "Make a call" function for OS2.

Task	Make a call	Complexity
1	Locate Phone Application	3.6
2	Response from Phone	1.01
3	Dial Numbers	9.2
4	Click Call	0.6
5	Response from Phone	0.97

Using the data collected, task graphs have been created for each of the functions completed on all the phones. Figure 14 shows the task graph for the "make a call" function from Table 8, where each subtask is represented by a circle containing Tn and the complexity τ, where n is the number of the task. Hence the set of complexity for the "send message" function is:

$$\tau = \{\tau_1, \tau_2, \tau_3, \tau_4, \tau_5, \tau_6, \tau_7\} = \{3.6, \tau_2, 1.01, 9.2, 0.6, \tau_6, 0.97\} \quad (8)$$

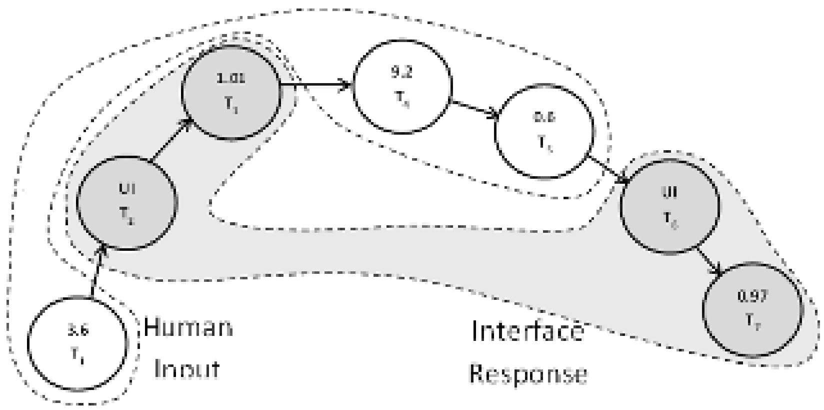

Figure 14. Task Graph for Make a Call function for OS2.

The tasks are divided into two areas: one representing the tasks completed by the smartphone, and the other representing the tasks completed by the user. Hence the allocation matrix for this function will have only two columns and will be represented by Equation (9):

$$A = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \\ a_{31} & a_{23} \\ a_{41} & a_{24} \\ a_{51} & a_{25} \\ a_{61} & a_{26} \\ a_{71} & a_{27} \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ 1 & 0 \\ 1 & 0 \\ 0 & 1 \\ 0 & 1 \\ 1 & 0 \\ 1 & 0 \end{bmatrix} \quad (9)$$

Some of the tasks which are completed by the smartphone interface had an unknown complexity and are hence labeled as "UI" denoting "user interface." These unknown complexities will be discussed in the next section.

The final step is setting up the data transfer matrix. The amount of data that is transferred from task n to task m is represented by the number of clicks given by the user in task n. The data transfer matrix will then be represented as:

$$F = \begin{bmatrix} 0 & f_{12} & f_{13} & f_{14} & f_{15} & f_{16} & f_{17} \\ f_{21} & 0 & f_{23} & f_{24} & f_{25} & f_{26} & f_{27} \\ f_{31} & f_{32} & 0 & f_{34} & f_{35} & f_{36} & f_{37} \\ f_{41} & f_{42} & f_{43} & 0 & f_{45} & f_{46} & f_{47} \\ f_{51} & f_{52} & f_{53} & f_{54} & 0 & f_{56} & f_{57} \\ f_{61} & f_{62} & f_{63} & f_{64} & f_{65} & 0 & f_{67} \\ f_{71} & f_{72} & f_{73} & f_{74} & f_{75} & f_{76} & 0 \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 11 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \quad (10)$$

4.1.2.2. Using Matlab for Computations of CIQ and HIQ

In order to complete the calculations discussed in the previous section, it is best to develop a program that can do so as accurately and as quickly as possible. Matlab has been chosen since it has an easy way to calculate matrices. Appendix C shows the two functions that were written in Matlab to do the calculations.

4.1.2.3. Calculating the UIQ

Using the data gathered, the CIQ can be calculated using Equation (5).

$$CIQ = 3.6 + \tau_2 + 1.01 + 9.2 + 0.6 + \tau_6 + 0.97 = 15.38 + \tau_2 + \tau_6 \quad (11)$$

The complexity of some tasks is unknown since they are completed by the device. Therefore, certain fixed values are set as the CIQ for each function and kept constant for all the phones in order to see the difference. The values chosen are an approximation of how much IQ a task would need for completion, and are listed in Table 9.

Table 9. CIQ values for functions.

Task	CIQ
Make a call	50
Send a message	200
Set an appointment	100
Go to webpage	50

The next step is calculating the HIQ using Equation (6), with the addition of two more variables: *Chm* and *Cmh*. As described by [15], these two indexes define the complexity of transferring data from human to machine and from machine to human, respectively. In order to obtain reasonable values for these indexes, two different methods have been used.

For *Chm*, the results of the lock and unlock experiment have been used, as this is the experiment which proves how easy or difficult is it for a user to transfer data to the device. The *Chm* values for the different devices are shown in Table 10.

For *Cmh*, the factor that has been considered is the time it took for the user to locate the certain applications on the phone in order to complete the tasks assigned. The average time taken to locate the applications defines how easy or difficult it is for the phone to transfer data to the user. The *Cmh* values for the different devices are also shown in Table 10.

Table 10. Cmh and Chm values for smartphones.

Smartphone	Chm	Cmh
OS1	0.28571	0.32085
OS2	0.20408	0.37945
OS3	0.38961	0.5021
OS4	0.22222	1.75188
OS5	0.17647	0.47028

The data gathered in Equation 6 can now be used to calculate the HIQ as shown:

$$\mathrm{HIQ} = 3.6 + 9.2 + 0.6 + 0.22\ (1 + 10 + 1) + 1.75(1) = 17.79 \qquad (12)$$

Using the previous results in Equation 7, the UIQ can finally be calculated:

$$\mathrm{UIQ} = 50 - 17.79 = 32.21 \qquad (13)$$

4.2. Fuzzy Logic

4.2.1. Fuzzy Interface System

In order to be able to evaluate the data collected from the experiments using fuzzy logic (FL), firstly we decide on the number of inputs and outputs to the FL system that would give us the desired result. Each task that was assigned in the experiments will have a separate FL system. This is because each task will have a different number of inputs. However, in order to maintain consistency when judging the different smartphones, each FL system will be the same for every task for all smartphones. Hence a total of four FL systems will be designed which are known as the Fuzzy Interface System, FIS.

There was no way to predict which model (Madmani or Sugeno) would work better for the UIQ calculation. Hence both methods were used and Madmani proved to be better in this case since it gave a better result than Sugeno.

When deciding on the inputs for the FIS, we considered the factors that affect the usability of the user interface. Using that idea these were the set of inputs used for each FIS:

1. Complexity of each subtask.
2. Interface response.
3. Total number of subtasks.
4. *Cmh* and *Chm*.

The complexity of each subtask was recorded in the experiments as the time taken to complete the subtasks. These complexities will account for the human input, as for the interface input it is handled by the interface response. Each task can have a different number of subtasks with different smartphones and since one FIS system is used for all smartphones, the number of subtasks is also considered an input. Finally the *Cmh* and *Chm* values, which were introduced in the previous section, also play a role in determining the UIQ.

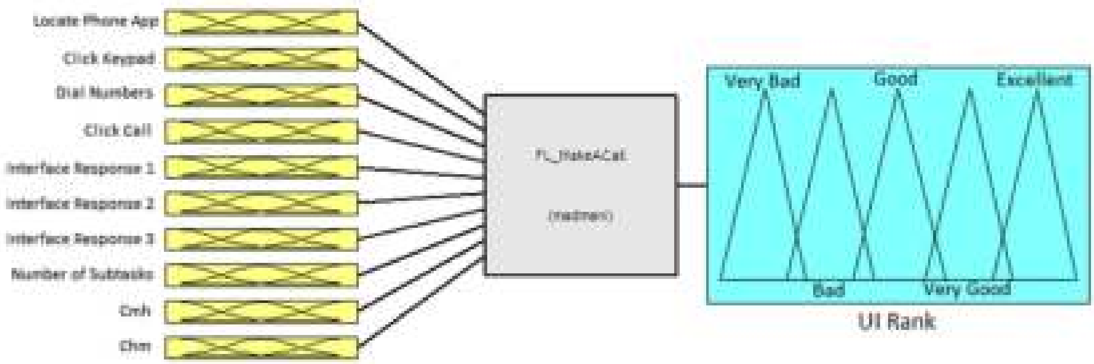

Figure 15. FIS for "Make a Call" Task.

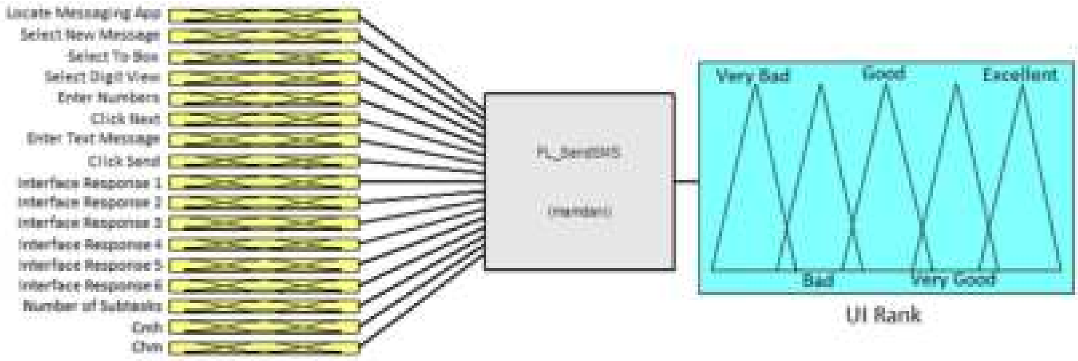

Figure 16. FIS for "Send SMS" Task.

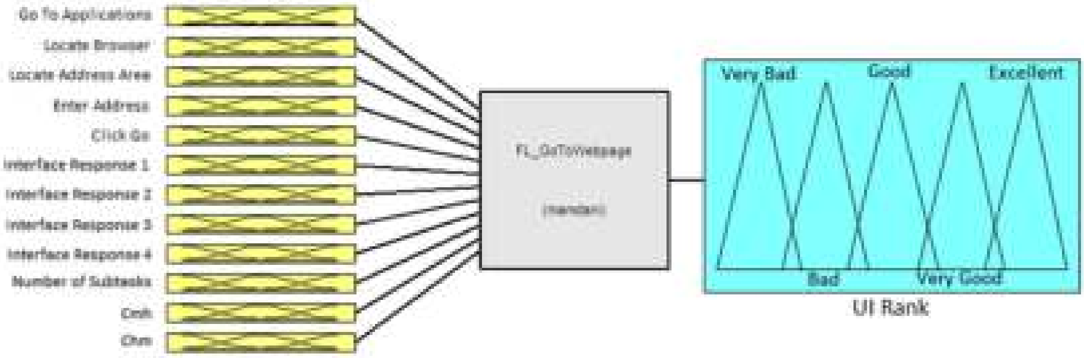

Figure 17. FIS for "Go to Webpage" Task.

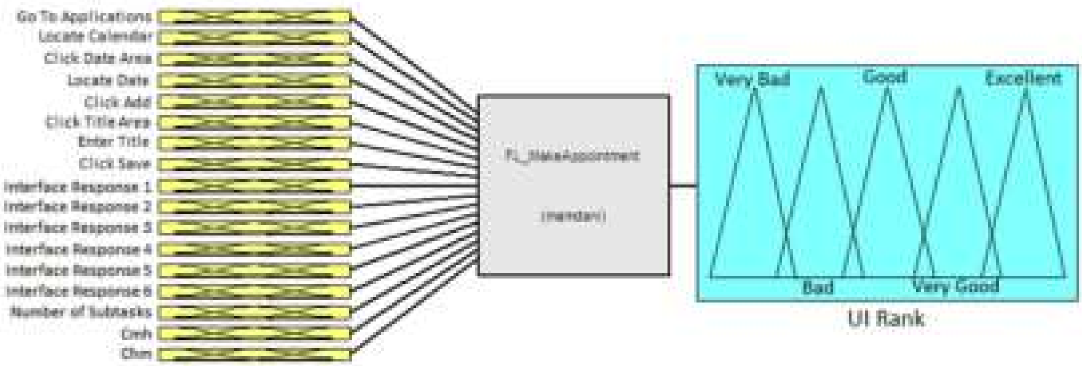

Figure 18. FIS for "Make Appointment" Task.

There is only one output in the FIS, which is what will be called the UI Rank. This output simply assigns each of the user interfaces a number that could be used as the UIQ. Figures 15 to 18 show the four FISs for each task.

4.2.2. Membership values and functions

The next step is to set up the membership functions and values for each input in the FISs. Each input contains 3 different membership functions classifying them as short, average, and long. The membership values range from the lowest complexity value of the 5 smartphones up to the maximum complexity value. Figures 19, 20 and 21 show three different inputs for the "make a call" task FIS. These inputs contain three membership functions each and each of these subtasks have different membership values assigned to their membership functions, each depending on the range of complexity. These values can be seen in Tables 11, 12 and 13.

The first input shown in Figure 19 is the “locate phone application” subtask. This input has three membership functions: short, average, and long representing the amount of time spent on the subtask (in this experiment known as the complexity). The membership values for these functions can be seen in Table 11.

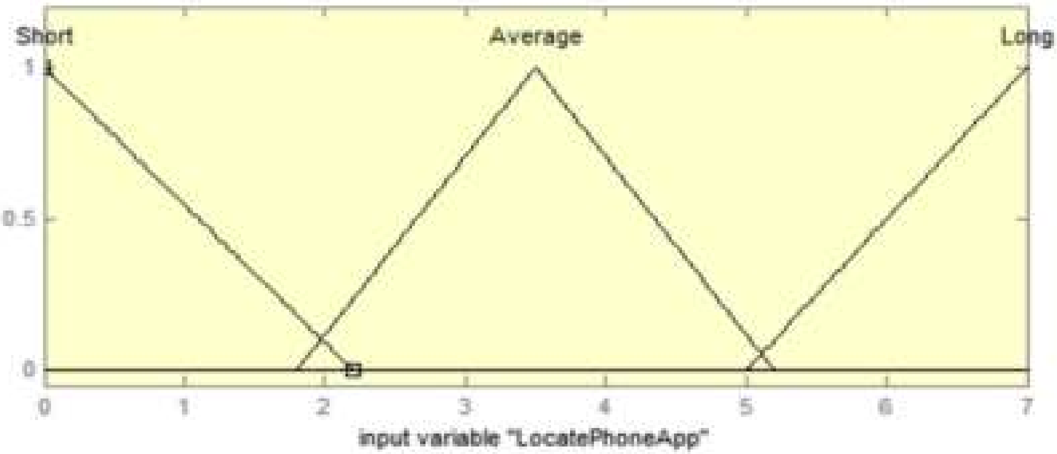

Figure 19. The membership values and functions for “locate phone application” subtask.

Table 11 Membership values for the membership functions of “locate phone applcation” input in the “make a call” task.

Input Field	Range	Fuzzy Sets
Locate Phone App	<2.2	Short
	1.8 - 5.2	Average
	>5	Long

The second input discussed is the one of interface responses. As seen in Figure 20, it contains three membership functions similar to the previous input; however the membership values are different as seen in Table 12.

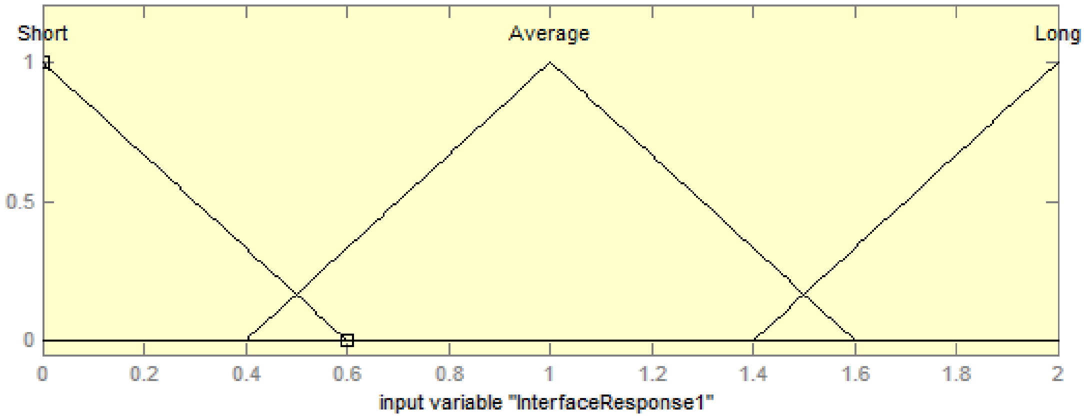

Figure 20. Membership values and functions for interface response 1.

Table 12. Membership values for the membership functions of interface response 1 input in "make a call" task.

Input Field	Range	Fuzzy Sets
Interface Response 1	<0.6	Short
	0.4 - 1.6	Average
	>1.4	Long

A final example is the *Cmh* input. As seen in the previous input, this input has only 3 membership functions as well; these are shown in Figure 21. The membership values, however, are different and can be seen in Table 13.

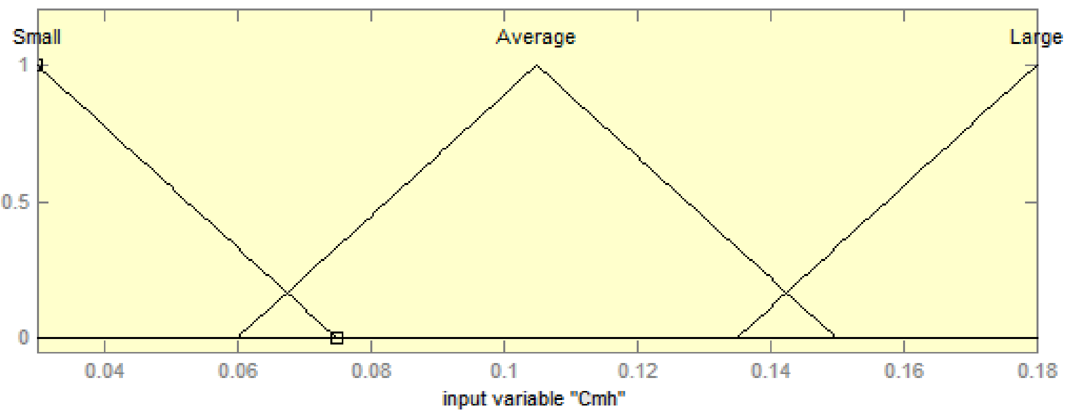

Figure 21. The membership values and functions for *Cmh*.

Table 13. Membership values for the membership functions of *Cmh* input in the "make a call" task.

Input Field	Range	Fuzzy Sets
Cmh	<0.075	Small
	0.06 - 0.15	Average
	>0.135	Large

These were only 3 sample inputs from the total of 12 inputs for the "make a call" task FIS. The output for this FIS is the same as all the FISs and it was called the UIQ Rank. The membership values of the output ranged from 0 – 100 and contained five different membership functions: very bad, bad, good, very good, and excellent. The lower the rank assigned, the higher the output value was. Figure 22 shows the membership functions. The membership values for these functions can be seen in Table 14.

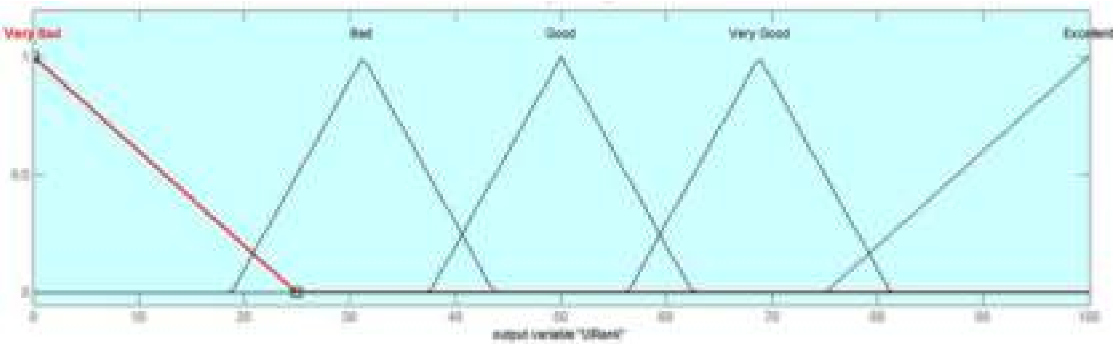

Figure 22. Membership function for the UI Rank output.

Table 14. Membership values for the membership functions of the UI Rank.

Output Field	Range	Fuzzy Sets
UIRank (Make A Call)	<25	Very Bad
	19 – 43	Bad
	38 – 62	Good
	57 – 81	Very Good
	>75	Excellent

4.2.3. Fuzzy Rules

After setting up all the membership functions and values of the inputs and outputs of the FIS, it was now time to set up the rules. Each FIS had the same set of rules. The number of rules for each FIS was calculated using Equation 14 [31].

$$N = p1 \times p2 \times p3 \times \ldots \times pn \tag{14}$$

where N is the total number of possible rules for a fuzzy system and *pn* is the number of linguistic terms for the input variable N. However, using this equation would result in 177147 rules for the "make a call" FIS, and an even larger number of rules for the other FISs. Since it would be unpractical to develop that many rules for each FIS, the following 15 rules were chosen after discussion with a fuzzy logic expert:

1. If [All Subtask complexities = Short] AND [All Interface Responses = Short]
   Then UIQ Rank = 1 (weight = 0.5)

2. If [All Subtask complexities = Long] AND [All Interface Responses = Long] Then UIQ Rank = 5 (weight = 0.5)
3. If [All Subtask complexities = Average] AND [All Interface Responses = Average] Then UIQ Rank = 3 (weight = 0.5)
4. If [All Interface Responses = Short] Then UIQ Rank = 2 (weight = 0.5)
5. If [All Interface Responses = Long] Then UIQ Rank = 4 (weight = 0.5)
6. If [Locating Application = Short] Then UIQ Rank = 2 (weight = 0.5)
7. If [Locating Application = Long] Then UIQ Rank = 4 (weight = 0.5)
8. If [Number of Tasks = Few] Then UIQ Rank = 1 (weight = 1)
9. If [Number of Tasks = More] Then UIQ Rank = 5 (weight = 1)
10. If [Cmh = Small] Then UIQ Rank = 1 (weight = 0.5)
11. If [Cmh = Large] Then UIQ Rank = 5 (weight = 0.5)
12. If [Cmh = Average]Then UIQ Rank = 2 (weight = 0.5)
13. If [Chm = Small] Then UIQ Rank = 1 (weight = 0.5)
14. If [Chm = Large] Then UIQ Rank = 5 (weight = 0.5)
15. If [Chm = Average] Then UIQ Rank = 2 (weight = 0.5)

Rules 1, 2, and 3 cover the bases that if all the complexities of the task as well as all the interface responses are short, long, or average then the rank will be 1, 5, or 3, respectively. Similarly, rules 4 and 5 take into consideration all the interface responses which represent how slow or fast the interface is in responding to the users' requests and assign the rank accordingly. On the other hand, rules 6 and 7 represent how easy a user interface is to understand. The faster it is to locate the application required, the shorter the complexity and the better the rank for the user interface. Rules 8 and 9 are very important and represent how many subtasks are required to complete the task at hand. Of course, the fewer the number of subtasks, the better the UIQ rank. Finally, rules 10 to 15 use the constants *Cmh* and *Chm* to rank the UIQ accordingly. It should be noted that before introducing these final six rules, the FIS result was far from accurate. Each of these rules has a weight which represents how important the rule is, and most of these weights were assigned according to trial and error.

4.2.4. Getting the UIQ

After preparing all the FISs for each task, the UIQ was calculated by opening the FIS and passing the data to it that was collected from the experiment. Below is the code for calculating the UIQ for the “make a call” task by OS2.

```
>> MakeACall = readfis('FL_MakeACall.fis')

MakeACall =
            name: 'FL_MakeACall'
            type: 'mamdani'
       andMethod: 'min'
        orMethod: 'max'
    defuzzMethod: 'centroid'
       impMethod: 'min'
       aggMethod: 'max'
           input: [1x10 struct]
          output: [1x1 struct]
            rule: [1x15 struct]

>>OS2_MakeACall_UIQ =
evalfis([3.6;0;9.2;0.6;1.01;0;0.97;5;0.18;0.022],MakeACall)

OS2_MakeACall_UIQ =
   59.3466
```

Repeating this step for all the tasks on all the smartphones, we were able to get the UIQ for all of them using the FISs developed.

4.2.5. Combining the UIQ of all the tasks

In the previous section we developed different FISs to acquire the UIQ of four different tasks. These results can be compared to the results from the UIQ metric developed in Section 4.1. However, unlike in the UIQ Metric method, fuzzy logic can be used to develop an overall UIQ for each smartphone depending on the results of each task from the FISs.

4.2.5.1. Development of new FISs

This section discusses the development of four additional FISs that would use the outputs from the previous FISs developed for each task. The first FIS is used to show the overall intelligence of each smartphone using only one input which is the output of the “make a call” task FIS. This new FIS will represent the overall intelligence of the smartphone when it comes to very basic use, which is only making a call. This output will be known as “phone smartness for very basic use” and refers to users who use their smartphones only for making calls. Figure 23 shows the setup of this FIS.

he second FIS represents the overall intelligence of each smartphone using two inputs, the output of the “make a call” task FIS and the “send a message” task FIS. This new FIS will represent the overall smartness of the smartphone when it comes to basic use, which is only making calls and sending messages. This output will be known as the “phone smartness for basic use” and refers to users who use their smartphones only for making calls and sending messages. The setup for this FIS is shown in Figure 24.

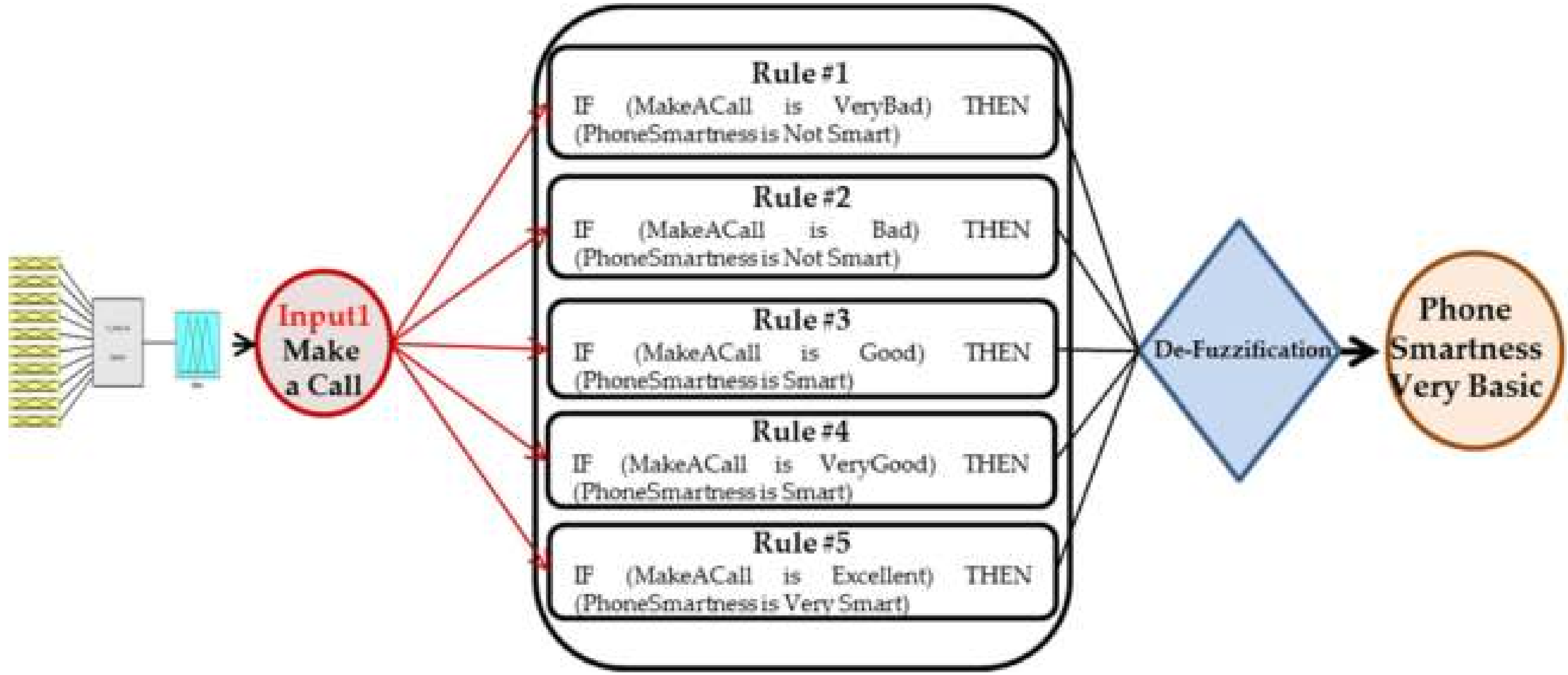

Figure 23. Setup of FIS for Very Basic Phone Smartness.

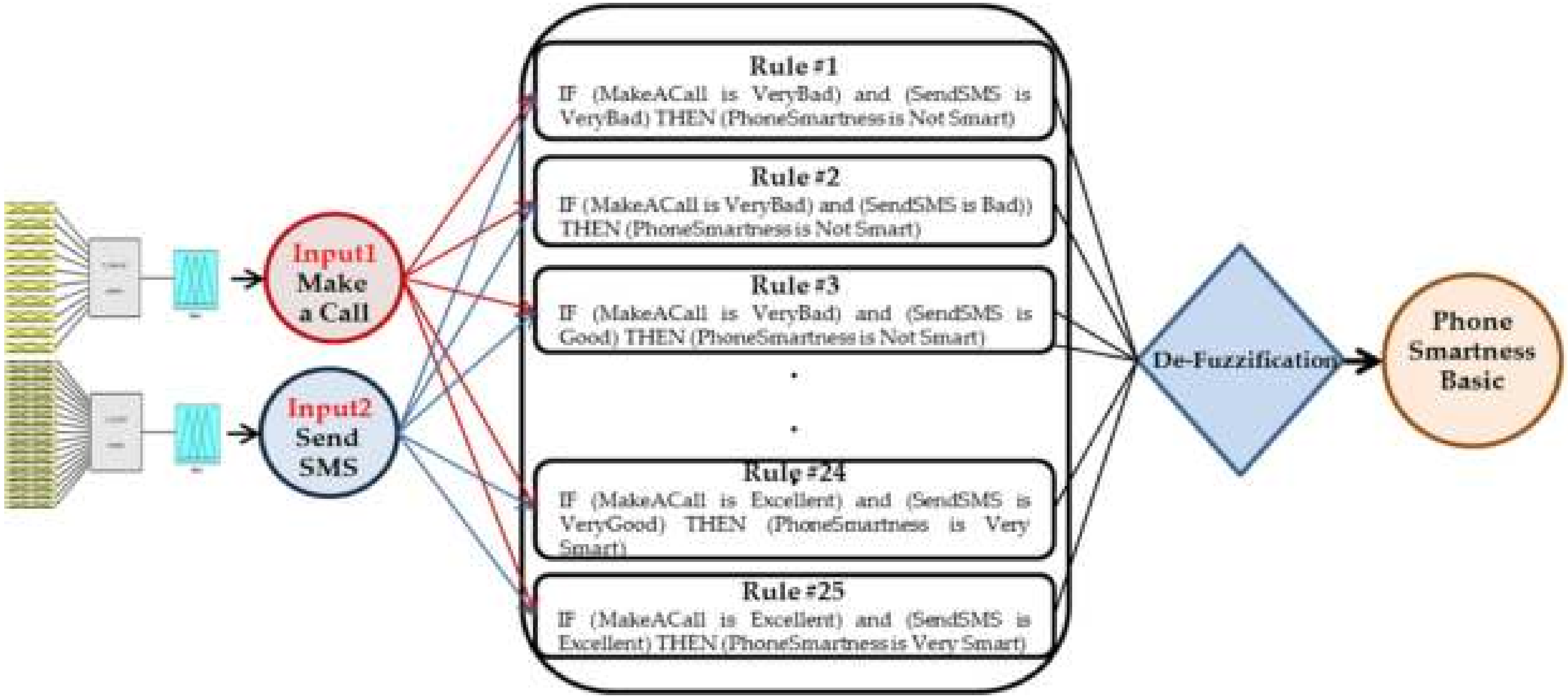

Figure 24. Setup of FIS for Basic Phone Smartness.

The third system shows the overall intelligence of each smartphone using three inputs, the outputs of the “make a call,” “send a message,” and “go to webpage” task FISs. This new FIS will represent the overall smartness of the smartphone when it comes to advanced use, which is making calls, sending messages, and using the internet browser. This output will be known as the “phone smartness for advanced use” and refers to users who use their smartphones for making calls, sending messages, and visiting webpages. The setup for this FIS is shown in Figure 25.

The final system uses all the four task outputs as inputs and shows the overall intelligence of each smartphone using them. Those inputs are the outputs of the “make a call,” “send a message,” “go to webpage,” and “make appointment” task FIS. This new FIS will represent the overall smartness of the smartphone when it comes to very advanced use, which is making calls, sending messages, using the internet browser, and setting appointments in the calendar. This output will be known as the “phone smartness for very advanced use” and refers to very advanced users who use their smartphones for making calls, sending messages, visiting webpages, and keeping track of appointments and important dates using the calendar. The setup for this FIS is shown in Figure 26.

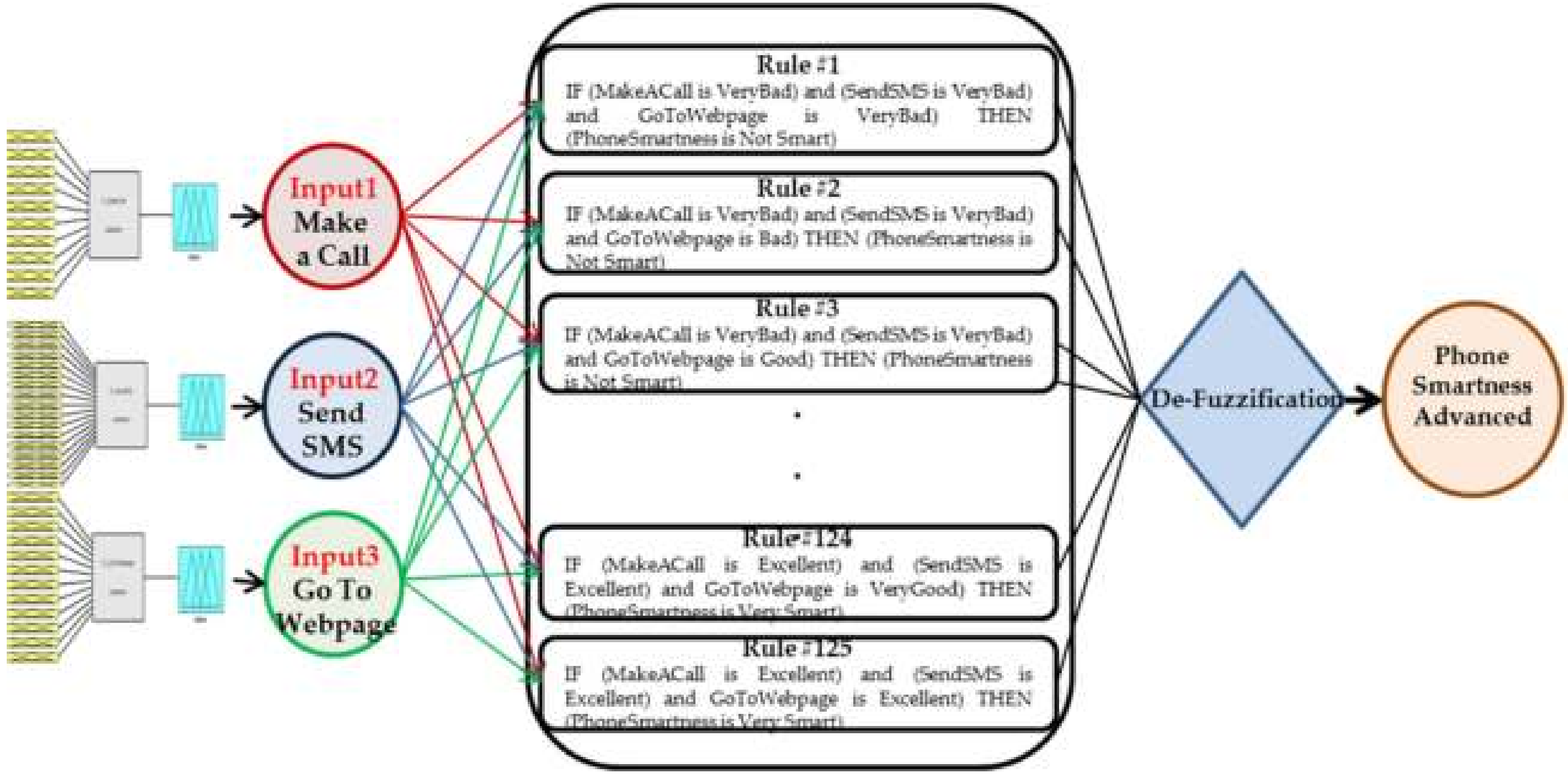

Figure 25. Setup of FIS for Advanced Phone Smartness.

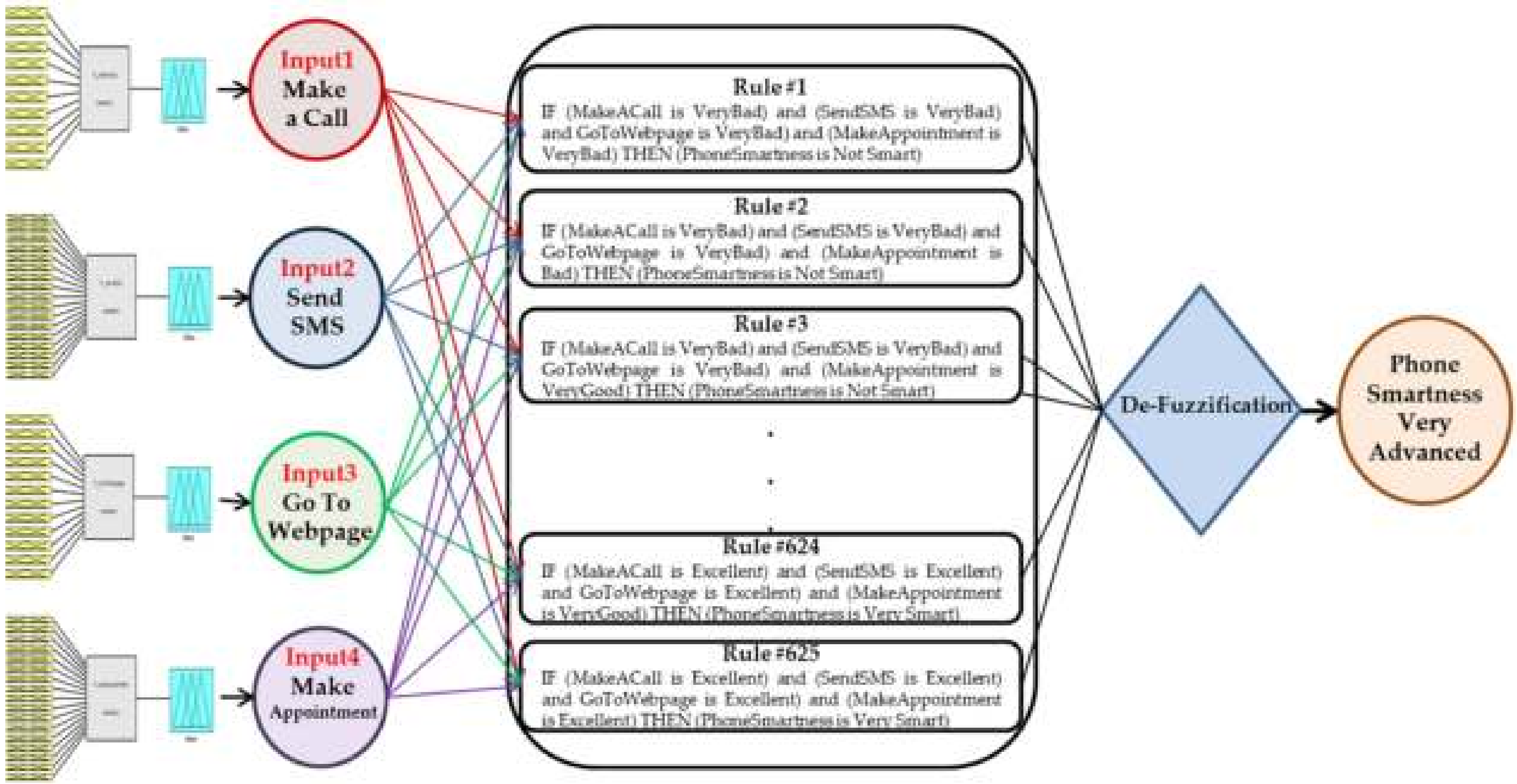

Figure 26. Setup of FIS for Very Advanced Phone Smartness.

Figures 22-26 show the overall setup of the FIS systems. Data flows from left to right. Starting from the left, the previously developed FISs are shown and their output is fed in as input to the new FIS. The inputs then enter the FIS where the rules are all stored in parallel. The inputs flow smoothly through all the rules and the results enter into the de-fuzzification stage which converts the crisp result into the results represented by the membership functions. The number of rules can be deduced again from Equation 14; however this time the number of rules is relatively small. The largest number of rules is 625 for the biggest FIS with 4 inputs. For these FISs all the possible rules were developed and a sample of these rules can be seen in Figure 27.

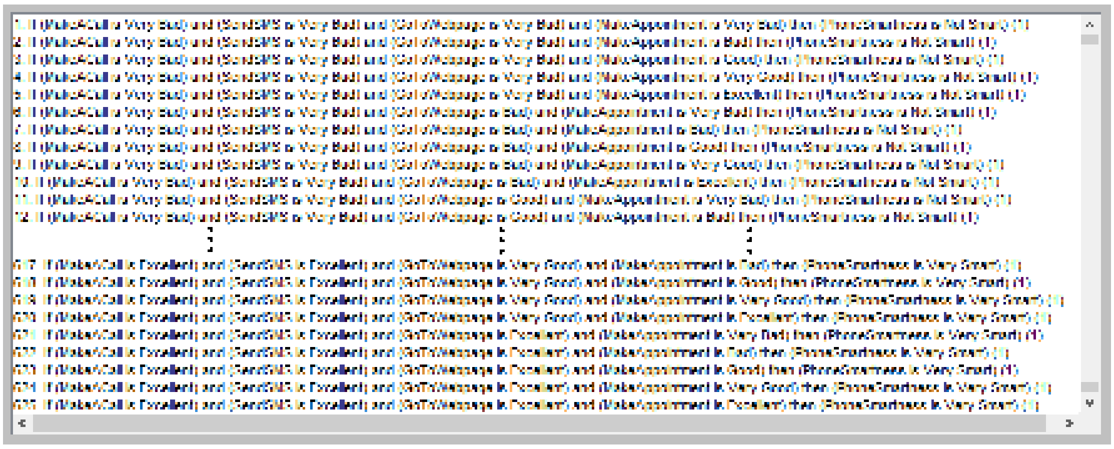

Figure 27. Sample rules for the Very Advanced Phone Smartness FIS.

The FIS for "very advanced phone smartness" can be seen in Figure 28. Its input and output membership functions and membership values can be seen in Figures 29 and 30 and Tables 15 and 16.

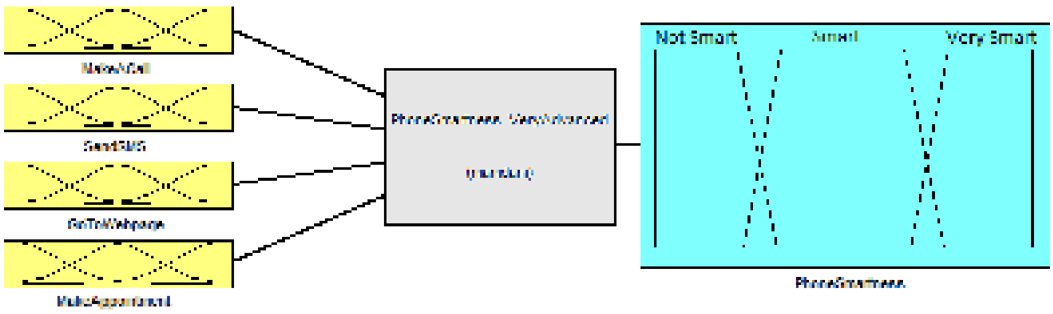

Figure 28. FIS for Very Advanced Phone Smartness.

One of the inputs is the output from the "make a call task" whose membership functions and values can be seen in Figure 27 and Table 15. The membership functions and values will be identical for the rest of the inputs since they were all taken from the output of the initially-developed FISs and they all had the same output.

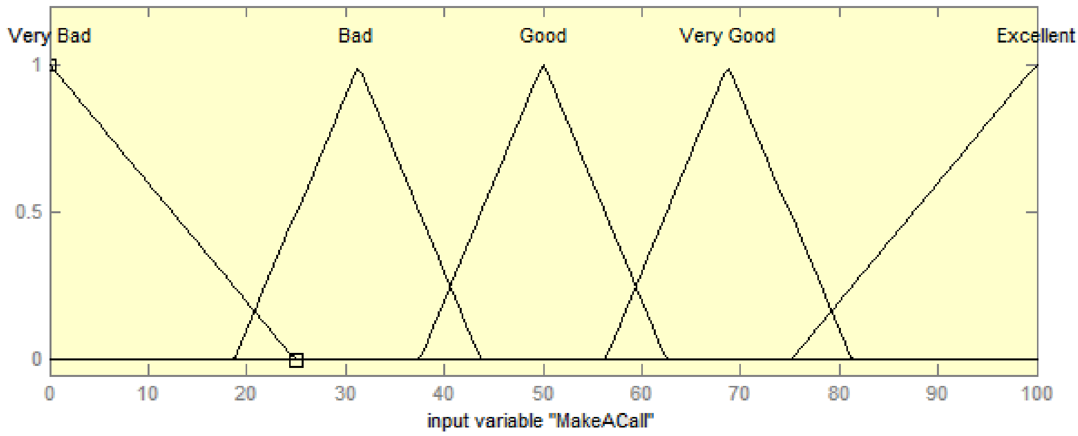

Figure 29. Membership functions for the "make a call" input of the Very Advanced Phone Smartness FIS.

Table 15. The membership functions for the "make a call" input of the Very Advanced Phone Smartness FIS.

Input Field	Range	Fuzzy Sets
Make A Call	<25	Very Bad
	19 – 43	Bad
	38 – 62	Good
	56 – 81	Very Good
	>75	Excellent

The output of the FIS is the same for all the new FISs. This is because they all give a result of the smartness level of the phones' UI. However, each of them gives it for a different set of inputs. The membership functions and values of the output can be seen in Figure 30 and Table 16.

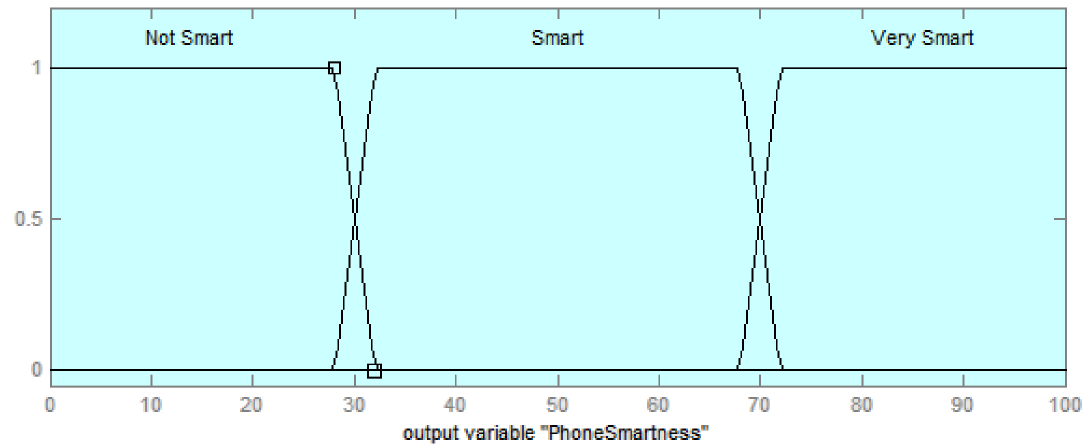

Figure 30. The output membership functions for the Very Advanced Phone Smartness FIS.

As seen in Figure 28, the output contains three membership functions: "not smart," "smart," and "very smart." This is the overall rating of the smartphone with the different criteria as inputs to the FIS. The range of the membership values is from 0 to 100.

Table 16. The output membership values for the Very Advanced Phone Smartness FIS.

Output Field	Range	Fuzzy Sets
Phone Smartness	<32	Not Smart
	28 - 72	Smart
	>68	Very Smart

4.2.5.2. Results from new FISs

Using the FISs discussed in the previous section, we were able to get the phone smartness rating for the four different cases: very basic, basic, advanced and very advanced. The results can be seen in Figure 31.

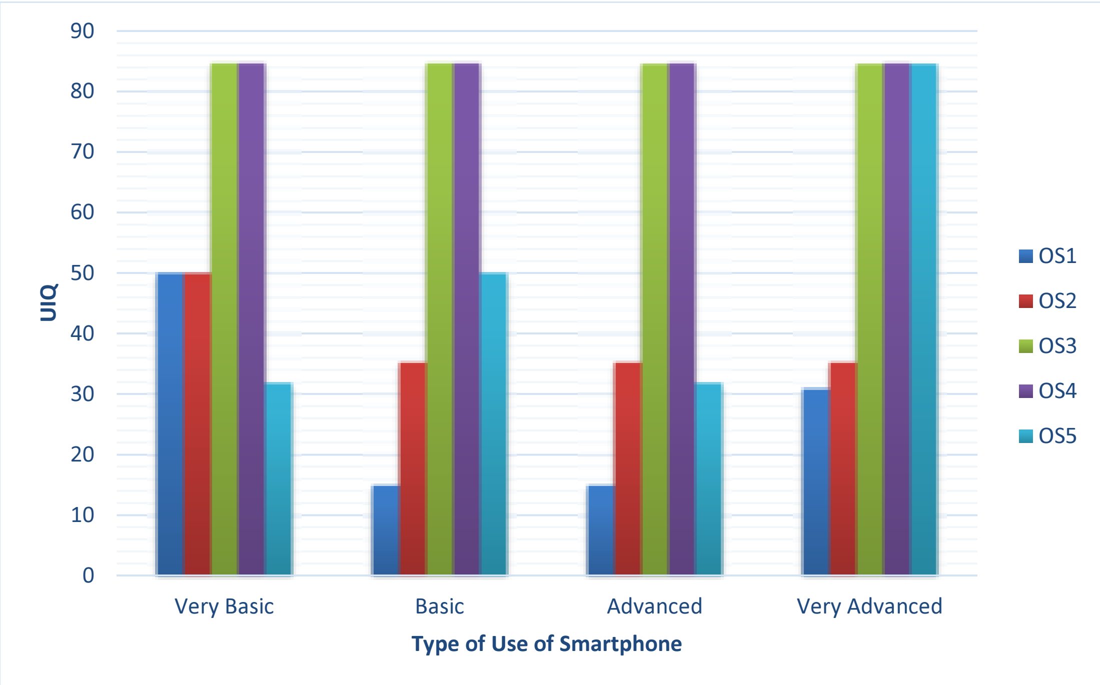

Figure 31. Results from the new FISs.

The first thing noticed from the results in Figure 31 are the results for OS3 and OS4. They have a high rating of "very smart" for all the criteria. So these phones would be suitable for any type of user, from very basic up to very advanced. OS1 received a rating of "smart" for very basic use; however, this rating falls to "not smart" when it comes to basic and advanced use. This means that sending messages and using the web is relatively harder on this OS than on the others. OS2 shows almost the same results as OS1, except that its rating is "smart" for all the criteria.

Finally, OS5 shows the most interesting results. It has a low rating when it comes to very basic and advanced use, but a high rating of "very smart" when it comes to very advanced use. This could be due to the fact that this OS is the hardest when it comes to making calls due to an extra subtask that is required. However, its calendar was relatively one of the easiest to use, which boosted its rating level for very advanced use.

These results are very interesting when it comes to users' different needs. Some users might need a phone for simple tasks such as making calls and sending messages, whereas others may have more complex demands. Clearly, these two types of users would have different reactions to the same OS and so when measuring the smartness of a device, these aspects should be considered.

4.2.6. Fuzzy Inference

A fuzzy inference is "the process of formulating the mapping from a given input to an output using fuzzy logic" [32]. The mapping then provides a basis from which decisions can be made, or patterns discerned. In this work, the fuzzy inference process is exemplified using one case an example. The example is explained below.

Example: (Make a Call: 85.8, Send SMS: 85.8, Go To Webpage: 85.8, Make Appointment: 64.4)

The first step in the inference process is to determine the inputs' membership degree in each of the appropriate fuzzy sets. This is done via membership functions. Each input in the proposed system has its own set of functions to calculate the degree to which each given input belongs to each of the fuzzy sets. The proposed system is built on 625 rules. Before the rules can be evaluated, the inputs must be fuzzified according to each of the linguistic sets.

The degree of membership μ for a given input (e.g., MakeACall = 85.8) can be determined from the following equations.

$$MakeACall_{VeryBad}(x) = \begin{cases} 1 & x = 0 \\ \frac{25-x}{25} & 0 < x < 25 \end{cases} \quad (15)$$

$$MakeACall_{Bad}(x) = \begin{cases} \frac{x-18.75}{12.5} & 18.75 \le x < 31.25 \\ 1 & x = 31.25 \\ \frac{43.75-x}{12.5} & 31.25 < x < 43.75 \end{cases} \quad (16)$$

$$MakeACall_{Good}(x) = \begin{cases} \frac{x-37.5}{12.5} & 37.5 \le x < 50 \\ 1 & x = 50 \\ \frac{62.5-x}{12.5} & 50 < x < 62.5 \end{cases} \quad (17)$$

$$MakeACall_{VeryGood}(x) = \begin{cases} \frac{x-56.25}{12.5} & 56.25 \le x < 68.75 \\ 1 & x = 68.75 \\ \frac{81.25-x}{12.5} & 68.75 < x < 81.25 \end{cases} \quad (18)$$

$$MakeACall_{Excellent}(x) = \begin{cases} \frac{x-75}{25} & 75 \le x < 100 \\ 1 & x = 100 \end{cases} \quad (19)$$

where

$MakeACall_{VeryBad}(x)$, $MakeACall_{Bad}(x)$, $MakeACall_{Good}(x)$, $MakeACall_{VeryGood}(x)$, and $MakeACall_{Excellent}(x)$ represent the equations that describe the membership functions of Very Bad, Bad, Good, Very Good, and Excellent, respectively, and are generated with the $MakeACall$ input. μ is the degree of membership, and x is the input value.

So for MakeACall = 80, μ will be determined using:

$$MakeACall_{Excellent}(80) = \frac{x-75}{25} = \frac{85.8-75}{25} = 0.432$$

Similar to the MakeACall input, the same set of equations is used to determine the SendSMS, GoToWebPage, and MakeAppointment inputs since they have the same ranges. The rest of the equations are presented in Appendix A. In this manner, each input is fuzzified over all the qualifying membership functions required by the rules. Table 17 shows the degree of membership for each input.

Table 17. Degree of membership for each input.

Make A Call		**Send SMS**		**Go To Webpage**		**Make Appointment**	
Very Bad	**0**	Very Bad	**0**	Very Bad	**0**	Very Bad	**0**
Bad	**0**	Bad	**0**	Bad	**0**	Bad	**0**
Good	**0**	Good	**0**	Good	**0**	Good	**0**
Very Good	**0**	Very Good	**0**	Very Good	**0**	Very Good	**0.652**
Excellent	**0.432**	Excellent	**0.432**	Excellent	**0.432**	Excellent	**0**

After fuzzifying the inputs, the second step is to determine the degree to which each part of the antecedent is satisfied for each rule. For this example, and referring back to the rules, the membership function weight should be plug in from Table 1. One rule will fire (rule number 288) which states:

If (MakeACall is Excellent) and SendSMS is Excellent) and (GoToWebpage is Excellent) and (MakeAppointment is VeryGood) then (PhoneSmartness is VerySmart)

A firing strength for each output membership function of each rule is computed. The logical products for each rule are inferred (min'd) before being passed on to the defuzzification process for crisp output generation. The firing strength of the VerySmart Output for Rule 288 is determined by:

Min(0.432, 0.432, 0.432, 0.652) = 0.432.

The centroid for each output membership function is determined by the trapezoid fuzzy number centroid formula [33]:

$$\widetilde{A} = (a, b, c, d) \text{ is } C_{\widetilde{A}} = \frac{c^2 + d^2 + cd - a^2 - b^2 - ab}{3(c + d - a - b)}$$

$$VerySmart\ Centroid = \frac{100^2 + 100^2 + (100)(100) - 68^2 - 72^2}{3(100 + 100 - 68 - 72)} = 84.97778$$

The last step is the defuzzification process. For this we need to rule's weight which is a number between 0 and 1 applied to the number given by the antecedent. The weight of all the proposed system's rules is 1 and therefore has no effect at all on the implication process.

The defuzzification of the data into a crisp output is accomplished using the fuzzy centroid algorithm. This method is used because it is the most predominant and spontaneously appealing method among the defuzzification methods. It is done by combining the results of the inference process and then computing the "fuzzy centroid" of the area [3]. The weighed strengths of each output member function are multiplied by their respective output membership function center points and summed. Finally, this area is divided by the sum of the weighed member function strengths, and the result is taken as the crisp output. The formula shown in Equation 11 is the fuzzy centroid formula [34].

$$Output = \frac{\sum_{i=1}^{n}(center_i \,.\, Strength_i)}{\sum_{i=1}^{n} Strength_i}$$

where n is the number of output members. Based on the above equation, the phone smartness (which is the output of the proposed system) will be:

$$PhoneSmartness = \frac{(0.432 \times 84.97778)}{0.432} = 84.97778$$

The same inputs were given similar results when they were computed using Matlab as shown in Figure 32.

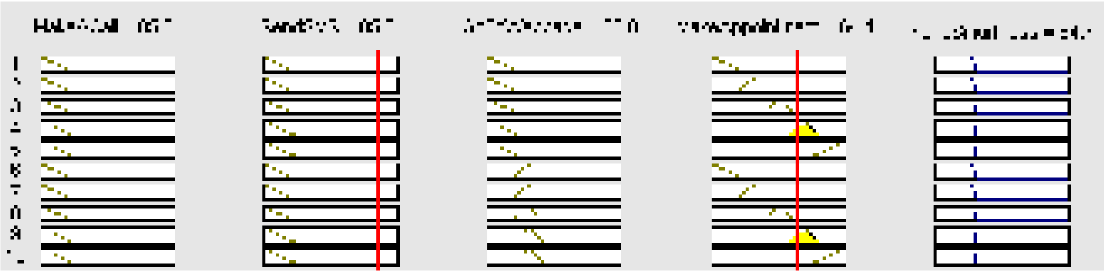

Figure 32. Obtaining result using Matlab.

Results using Matlab $= 84.7$

Results using calculations $= 84.978$

Error $= 84.978 - 84.7 = 0.278$

This shows that the matlab results have a small error when compared to the calculation. This is important to insure that there are no other factors affecting the difference of results between the different methods.

Chapter 5: Compilation of the Results

5.1. Calculating UIQ using the UIQ Metric:

In this section UIQ for each operating system will be calculated using the task graph and the parameters acquired during the experimental sessions.

5.1.1. Calculations for OS1

This section shows the calculation of the UIQ for OS1. When calculating the UIQ for each task, its task graph is used to work out all the complexities of its subtasks and then build on that basis the task set, complexity set, data transfer matrix, and task allocation matrix. Below is the step-by-step calculation of the “go to webpage” task on OS1. Figure 33 shows the task graph for the “go to webpage” task and Table 18 shows the list of subtasks and their complexities.

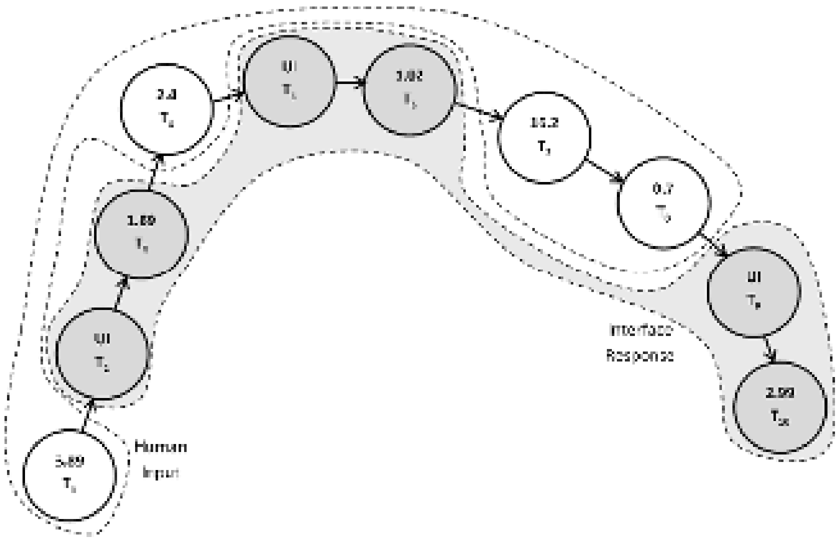

Figure 33. OS1 “go to webpage” task graph.

Table 18. OS1 "go to webpage" subtask complexities.

Task	Go To Webpage	Average
1	Locate Browser	3.888889
2	Response from Phone	UI
3	Response from Phone	1.89
4	Locate Address Area	2.4
5	Response from Phone	UI
6	Response from Phone	1.02
7	Enter Address	16.2
8	Click on Go	0.7
9	Response from Phone	UI
10	Response from Phone	2.99

Task Set:

$T = \{T_1, T_2, T_3, T_4, T_5, T_6, T_7, T_8, T_9, T_{10}\}$

Difficulty Set:

$\tau = \{\tau_1, \tau_2, \tau_3, \tau_4, \tau_5, \tau_6, \tau_7, \tau_8, \tau_9, \tau_{10}\}$

$\tau = \{3.89, \tau_2, 1.89, 2.4, \tau_5, 1.02, 16.2, 0.7, \tau_9, 2.99\}$

Data Transfer Matrix:

$$F = \begin{bmatrix} 0 & f_{12} & f_{13} & f_{14} & f_{15} & f_{16} & f_{17} & f_{18} & f_{19} & f_{110} \\ f_{21} & 0 & f_{23} & f_{24} & f_{25} & f_{26} & f_{27} & f_{28} & f_{29} & f_{210} \\ f_{31} & f_{32} & 0 & f_{34} & f_{35} & f_{36} & f_{37} & f_{38} & f_{39} & f_{310} \\ f_{41} & f_{42} & f_{43} & 0 & f_{45} & f_{46} & f_{47} & f_{48} & f_{49} & f_{410} \\ f_{51} & f_{52} & f_{53} & f_{54} & 0 & f_{56} & f_{57} & f_{58} & f_{59} & f_{510} \\ f_{61} & f_{62} & f_{63} & f_{64} & f_{65} & 0 & f_{67} & f_{68} & f_{69} & f_{610} \\ f_{71} & f_{72} & f_{73} & f_{74} & f_{75} & f_{76} & 0 & f_{78} & f_{79} & f_{710} \\ f_{81} & f_{82} & f_{83} & f_{84} & f_{85} & f_{86} & f_{87} & 0 & f_{89} & f_{810} \\ f_{91} & f_{92} & f_{93} & f_{94} & f_{95} & f_{96} & f_{97} & f_{98} & 0 & f_{910} \\ f_{101} & f_{102} & f_{103} & f_{104} & f_{105} & f_{106} & f_{107} & f_{108} & f_{109} & 0 \end{bmatrix}$$

$$= \begin{bmatrix} 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 11 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

Task Allocation Matrix:

$$A = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \\ a_{31} & a_{32} \\ a_{41} & a_{42} \\ a_{51} & a_{52} \\ a_{61} & a_{62} \\ a_{71} & a_{72} \\ a_{81} & a_{82} \\ a_{91} & a_{92} \\ a_{101} & a_{102} \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ 1 & 0 \\ 1 & 0 \\ 0 & 1 \\ 1 & 0 \\ 1 & 0 \\ 0 & 1 \\ 0 & 1 \\ 1 & 0 \\ 1 & 0 \end{bmatrix}$$

Using the Matlab HIQ function with the above data we get: **HIQ = 29.644** hence **UIQ = 50 – 29.644 = 20.356**

The calculation of UIQ of all the other tasks on OS1 can be seen in Appendix C.

5.1.2. Calculations for OS2

This section shows the calculation of the UIQ for OS2. When calculating the UIQ for each task, the OS task graph is used to work out all the complexities of its subtasks and then build on that basis the task set, complexity set, data transfer matrix, and task allocation matrix. Below is the step-by-step calculation of the "go to webpage" task on OS2. Figure 34. shows the task graph for the "go to webpage" task and Table 19 shows the list of subtasks and their complexities.

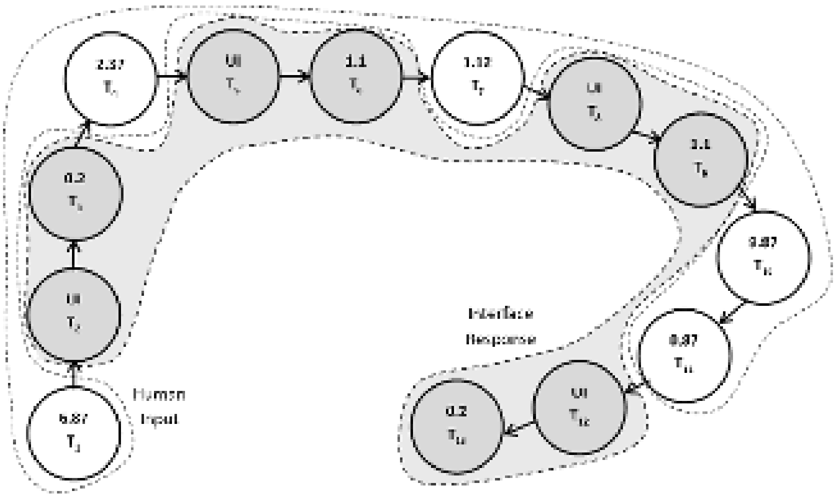

Figure 34. OS2 "go to webpage" task graph.

Table 19. OS2 "go to webpage" subtask complexities.

Task	Go To Webpage	Average
1	Click on Applications	6.875
2	Response from Phone	UI
3	Response from Phone	0.2
4	Locate Browser	2.375
5	Response from Phone	UI
6	Response from Phone	1.1
7	Locate Address Area	1.125
8	Response from Phone	UI
9	Response from Phone	1.1
10	Enter Address	9.875
11	Click on Go	0.875
12	Response from Phone	UI
13	Response from Phone	0.2

Task Set:

$T = \{T_1, T_2, T_3, T_4, T_5, T_6, T_7, T_8, T_9, T_{10}, T_{11}, T_{12}, T_{13}\}$

Difficulty Set:

$\tau = \{\tau_1, \tau_2, \tau_3, \tau_4, \tau_5, \tau_6, \tau_7, \tau_8, \tau_9, \tau_{10}, \tau_{11}, \tau_{12}, \tau_{13}\}$

$\tau = \{8.875, \tau_2, 0.2, 2.375, \tau_5, 1.1, 1.125, \tau_8, 1.1, 9.875, 0.875, \tau_{12}, 0.2\}$

Data Transfer Matrix:

$$F = \begin{bmatrix} 0 & f_{12} & f_{13} & f_{14} & f_{15} & f_{16} & f_{17} & f_{18} & f_{19} & f_{110} & f_{111} & f_{112} & f_{113} \\ f_{21} & 0 & f_{23} & f_{24} & f_{25} & f_{26} & f_{27} & f_{28} & f_{29} & f_{210} & f_{211} & f_{212} & f_{213} \\ f_{31} & f_{32} & 0 & f_{34} & f_{35} & f_{36} & f_{37} & f_{38} & f_{39} & f_{310} & f_{311} & f_{312} & f_{313} \\ f_{41} & f_{42} & f_{43} & 0 & f_{45} & f_{46} & f_{47} & f_{48} & f_{49} & f_{410} & f_{411} & f_{412} & f_{413} \\ f_{51} & f_{52} & f_{53} & f_{54} & 0 & f_{56} & f_{57} & f_{58} & f_{59} & f_{510} & f_{511} & f_{512} & f_{513} \\ f_{61} & f_{62} & f_{63} & f_{64} & f_{65} & 0 & f_{67} & f_{68} & f_{69} & f_{610} & f_{611} & f_{612} & f_{613} \\ f_{71} & f_{72} & f_{73} & f_{74} & f_{75} & f_{76} & 0 & f_{78} & f_{79} & f_{710} & f_{711} & f_{712} & f_{713} \\ f_{81} & f_{82} & f_{83} & f_{84} & f_{85} & f_{86} & f_{87} & 0 & f_{89} & f_{810} & f_{811} & f_{812} & f_{813} \\ f_{91} & f_{92} & f_{93} & f_{94} & f_{95} & f_{96} & f_{97} & f_{98} & 0 & f_{910} & f_{911} & f_{912} & f_{913} \\ f_{101} & f_{102} & f_{103} & f_{104} & f_{105} & f_{106} & f_{107} & f_{108} & f_{109} & 0 & f_{1010} & f_{1011} & f_{1013} \\ f_{111} & f_{112} & f_{113} & f_{114} & f_{115} & f_{116} & f_{117} & f_{118} & f_{119} & f_{1110} & 0 & f_{1112} & f_{1113} \\ f_{121} & f_{122} & f_{123} & f_{124} & f_{125} & f_{126} & f_{127} & f_{128} & f_{129} & f_{1210} & f_{1211} & 0 & f_{1213} \\ f_{131} & f_{132} & f_{133} & f_{134} & f_{135} & f_{136} & f_{137} & f_{138} & f_{139} & f_{1310} & f_{1311} & f_{1312} & 0 \end{bmatrix}$$

$$= \begin{bmatrix} 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 11 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

Task Allocation Matrix:

$$A = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \\ a_{31} & a_{32} \\ a_{41} & a_{42} \\ a_{51} & a_{52} \\ a_{61} & a_{62} \\ a_{71} & a_{72} \\ a_{81} & a_{82} \\ a_{91} & a_{92} \\ a_{101} & a_{102} \\ a_{111} & a_{112} \\ a_{121} & a_{122} \\ a_{131} & a_{132} \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ 1 & 0 \\ 1 & 0 \\ 0 & 1 \\ 1 & 0 \\ 1 & 0 \\ 0 & 1 \\ 1 & 0 \\ 1 & 0 \\ 0 & 1 \\ 0 & 1 \\ 1 & 0 \\ 1 & 0 \end{bmatrix}$$

Using the Matlab HIQ function with the above data we get: **HIQ = 29.695** hence **UIQ = 50 – 29.695 = 20.305**

The calculation of UIQ of all the other tasks on OS2 can be seen in Appendix C.

5.1.3. Calculations for OS3

This section shows the calculation of the UIQ for OS3. When calculating the UIQ for each task, its task graph is used to work out all the complexities of its subtasks and then build on that basis the task set, complexity set, data transfer matrix, and task allocation matrix. Below is the step-by-step calculation of the "go to webpage" task on OS3. Figure 35 shows the task graph for the "go to webpage" task and Table 20 shows the list of subtasks and their complexities.

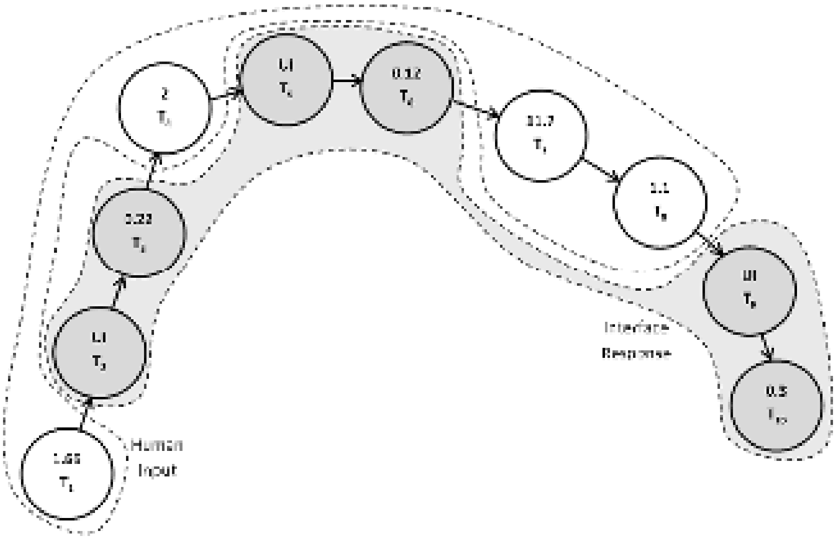

Figure 35. OS3 "go to webpage" task graph.

Table 20. OS3 go to webpage subtask complexities.

Task	Go To Webpage	Average
1	Locate Browser	1.666667
2	Response from Phone	UI
3	Response from Phone	0.22
4	Locate Address Area	2
5	Response from Phone	UI
6	Response from Phone	0.12
7	Enter Address	11.7
8	Click on Go	1.1
9	Response from Phone	UI
10	Response from Phone	0.3

Task Set:

$T = \{T_1, T_2, T_3, T_4, T_5, T_6, T_7, T_8, T_9, T_{10}\}$

Difficulty Set:

$\tau = \{\tau_1, \tau_2, \tau_3, \tau_4, \tau_5, \tau_6, \tau_7, \tau_8, \tau_9, \tau_{10}\}$

τ = {1.667, τ_2, 0.22, 2, τ_5, 0.12, 11.7, 1.1, τ_9, 0.3}

Data Transfer Matrix:

$$F = \begin{bmatrix} 0 & f_{12} & f_{13} & f_{14} & f_{15} & f_{16} & f_{17} & f_{18} & f_{19} & f_{110} \\ f_{21} & 0 & f_{23} & f_{24} & f_{25} & f_{26} & f_{27} & f_{28} & f_{29} & f_{210} \\ f_{31} & f_{32} & 0 & f_{34} & f_{35} & f_{36} & f_{37} & f_{38} & f_{39} & f_{310} \\ f_{41} & f_{42} & f_{43} & 0 & f_{45} & f_{46} & f_{47} & f_{48} & f_{49} & f_{410} \\ f_{51} & f_{52} & f_{53} & f_{54} & 0 & f_{56} & f_{57} & f_{58} & f_{59} & f_{510} \\ f_{61} & f_{62} & f_{63} & f_{64} & f_{65} & 0 & f_{67} & f_{68} & f_{69} & f_{610} \\ f_{71} & f_{72} & f_{73} & f_{74} & f_{75} & f_{76} & 0 & f_{78} & f_{79} & f_{710} \\ f_{81} & f_{82} & f_{83} & f_{84} & f_{85} & f_{86} & f_{87} & 0 & f_{89} & f_{810} \\ f_{91} & f_{92} & f_{93} & f_{94} & f_{95} & f_{96} & f_{97} & f_{98} & 0 & f_{910} \\ f_{101} & f_{102} & f_{103} & f_{104} & f_{105} & f_{106} & f_{107} & f_{108} & f_{109} & 0 \end{bmatrix}$$

$$= \begin{bmatrix} 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 11 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

Task Allocation Matrix:

$$A = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \\ a_{31} & a_{32} \\ a_{41} & a_{42} \\ a_{51} & a_{52} \\ a_{61} & a_{62} \\ a_{71} & a_{72} \\ a_{81} & a_{82} \\ a_{91} & a_{92} \\ a_{101} & a_{102} \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ 1 & 0 \\ 1 & 0 \\ 0 & 1 \\ 1 & 0 \\ 1 & 0 \\ 0 & 1 \\ 0 & 1 \\ 1 & 0 \\ 1 & 0 \end{bmatrix}$$

Using the Matlab HIQ function with the above data we get: **HIQ = 21.107** hence **UIQ = 50 – 21.107= 28.893**

The calculation of UIQ of all the other tasks on OS3 can be seen in Appendix C.

5.1.4. Calculations for OS4

This section shows the calculation of the UIQ for OS4. When calculating the UIQ for each task, its task graph is used to work out all the complexities of its subtasks and then build on that basis the task set, complexity set, data transfer matrix, and task allocation matrix. Below is the step-by-step calculation of the "go to webpage" task on OS4. Figure 36 shows the task graph for the "go to webpage" task and Table 21 shows the list of subtasks and their complexities.

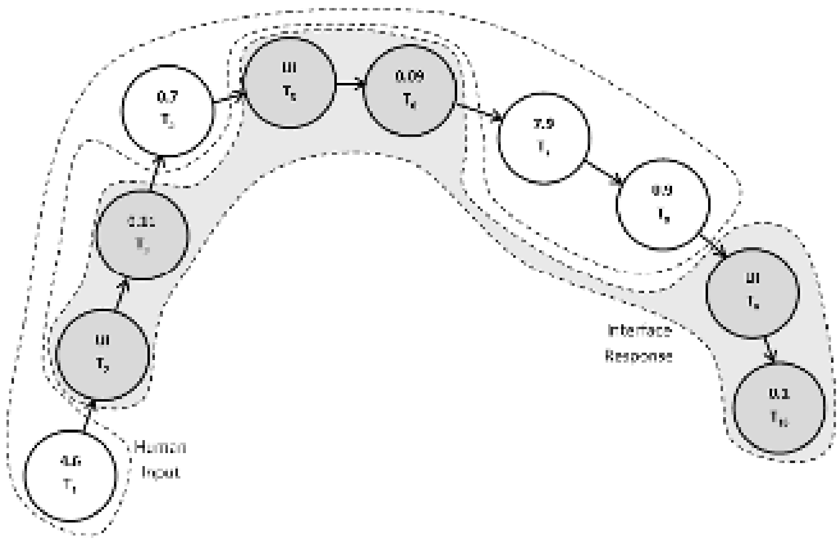

Figure 36. OS4 "go to webpage" task graph.

Table 21 OS4 "go to webpage" subtask complexities.

Task	Go To Webpage	Average
1	Locate Browser	4.6
2	Response from Phone	UI
3	Response from Phone	0.11
4	Locate Address Area	0.7
5	Response from Phone	UI
6	Response from Phone	0.09
7	Enter Address	7.9
8	Click on Go	0.9
9	Response from Phone	UI
10	Response from Phone	0.1

Task Set:

$T = \{T_1, T_2, T_3, T_4, T_5, T_6, T_7, T_8, T_9, T_{10}\}$

Difficulty Set:

$\tau = \{\tau_1, \tau_2, \tau_3, \tau_4, \tau_5, \tau_6, \tau_7, \tau_8, \tau_9, \tau_{10}\}$

$\tau = \{1.667, \tau_2, 0.22, 2, \tau_5, 0.12, 11.7, 1.1, \tau_9, 0.3\}$

Data Transfer Matrix:

$$F = \begin{bmatrix} 0 & f_{12} & f_{13} & f_{14} & f_{15} & f_{16} & f_{17} & f_{18} & f_{19} & f_{110} \\ f_{21} & 0 & f_{23} & f_{24} & f_{25} & f_{26} & f_{27} & f_{28} & f_{29} & f_{210} \\ f_{31} & f_{32} & 0 & f_{34} & f_{35} & f_{36} & f_{37} & f_{38} & f_{39} & f_{310} \\ f_{41} & f_{42} & f_{43} & 0 & f_{45} & f_{46} & f_{47} & f_{48} & f_{49} & f_{410} \\ f_{51} & f_{52} & f_{53} & f_{54} & 0 & f_{56} & f_{57} & f_{58} & f_{59} & f_{510} \\ f_{61} & f_{62} & f_{63} & f_{64} & f_{65} & 0 & f_{67} & f_{68} & f_{69} & f_{610} \\ f_{71} & f_{72} & f_{73} & f_{74} & f_{75} & f_{76} & 0 & f_{78} & f_{79} & f_{710} \\ f_{81} & f_{82} & f_{83} & f_{84} & f_{85} & f_{86} & f_{87} & 0 & f_{89} & f_{810} \\ f_{91} & f_{92} & f_{93} & f_{94} & f_{95} & f_{96} & f_{97} & f_{98} & 0 & f_{910} \\ f_{101} & f_{102} & f_{103} & f_{104} & f_{105} & f_{106} & f_{107} & f_{108} & f_{109} & 0 \end{bmatrix}$$

$$= \begin{bmatrix} 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 11 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

Task Allocation Matrix:

$$A = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \\ a_{31} & a_{32} \\ a_{41} & a_{42} \\ a_{51} & a_{52} \\ a_{61} & a_{62} \\ a_{71} & a_{72} \\ a_{81} & a_{82} \\ a_{91} & a_{92} \\ a_{101} & a_{102} \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ 1 & 0 \\ 1 & 0 \\ 0 & 1 \\ 1 & 0 \\ 1 & 0 \\ 0 & 1 \\ 0 & 1 \\ 1 & 0 \\ 1 & 0 \end{bmatrix}$$

Using the Matlab HIQ function with the above data we get: **HIQ = 17.658** hence **UIQ = 50 – 17.658 = 32.342**

The calculation of UIQ of all the other tasks on OS4 can be seen in Appendix C.

5.1.5. Calculations for OS5

This section shows the calculation of the UIQ for OS5. When calculating the UIQ for each task, its task graph is used to work out all the complexities of its subtasks and then build on that basis the task set, complexity set, data transfer matrix, and task allocation matrix. Below is the step-by-step calculation of the "go to webpage” task on OS5. Figure 37 shows the task graph for the “go to webpage” task and Table 22 shows the list of subtasks and their complexities.

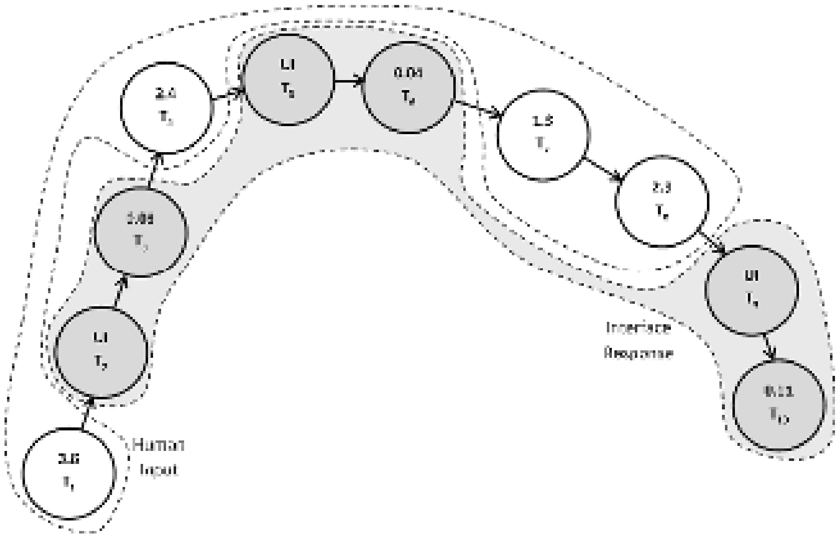

Figure 37. OS5 “go to webpage” task graph.

Table 22. OS5 “go to webpage” subtask complexities.

Task	Go To Webpage	Average
1	Locate Browser	3.8
2	Response from Phone	UI
3	Response from Phone	0.09
4	Locate Address Area	2.4
5	Response from Phone	UI
6	Response from Phone	0.04
7	Enter Address	8.3
8	Click on Go	2.9
9	Response from Phone	UI
10	Response from Phone	0.11

Task Set:

$T = \{T_1, T_2, T_3, T_4, T_5, T_6, T_7, T_8, T_9, T_{10}\}$

Difficulty Set:

$\tau = \{\tau_1, \tau_2, \tau_3, \tau_4, \tau_5, \tau_6, \tau_7, \tau_8, \tau_9, \tau_{10}\}$

$\tau = \{3.8, \tau_2, 0.09, 2.4, \tau_5, 0.04, 8.3, 2.9, \tau_9, 0.11\}$

Data Transfer Matrix:

$$F = \begin{bmatrix} 0 & f_{12} & f_{13} & f_{14} & f_{15} & f_{16} & f_{17} & f_{18} & f_{19} & f_{110} \\ f_{21} & 0 & f_{23} & f_{24} & f_{25} & f_{26} & f_{27} & f_{28} & f_{29} & f_{210} \\ f_{31} & f_{32} & 0 & f_{34} & f_{35} & f_{36} & f_{37} & f_{38} & f_{39} & f_{310} \\ f_{41} & f_{42} & f_{43} & 0 & f_{45} & f_{46} & f_{47} & f_{48} & f_{49} & f_{410} \\ f_{51} & f_{52} & f_{53} & f_{54} & 0 & f_{56} & f_{57} & f_{58} & f_{59} & f_{510} \\ f_{61} & f_{62} & f_{63} & f_{64} & f_{65} & 0 & f_{67} & f_{68} & f_{69} & f_{610} \\ f_{71} & f_{72} & f_{73} & f_{74} & f_{75} & f_{76} & 0 & f_{78} & f_{79} & f_{710} \\ f_{81} & f_{82} & f_{83} & f_{84} & f_{85} & f_{86} & f_{87} & 0 & f_{89} & f_{810} \\ f_{91} & f_{92} & f_{93} & f_{94} & f_{95} & f_{96} & f_{97} & f_{98} & 0 & f_{910} \\ f_{101} & f_{102} & f_{103} & f_{104} & f_{105} & f_{106} & f_{107} & f_{108} & f_{109} & 0 \end{bmatrix}$$

$$= \begin{bmatrix} 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 11 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

Task Allocation Matrix:

$$A = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \\ a_{31} & a_{32} \\ a_{41} & a_{42} \\ a_{51} & a_{52} \\ a_{61} & a_{62} \\ a_{71} & a_{72} \\ a_{81} & a_{82} \\ a_{91} & a_{92} \\ a_{101} & a_{102} \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ 1 & 0 \\ 1 & 0 \\ 0 & 1 \\ 1 & 0 \\ 1 & 0 \\ 0 & 1 \\ 0 & 1 \\ 1 & 0 \\ 1 & 0 \end{bmatrix}$$

Using the Matlab HIQ function with the above data we get: **HIQ = 20.805** hence **UIQ = 50 – 20.805 = 29.195**

The calculation of UIQ of all the other tasks on OS5 can be seen in Appendix C.

5.2. Calculating UIQ using Fuzzy Logic

In this section UIQ value is calculated using a fuzzy logic system. The parameters used in this system are exactly the same parameters determined through the experimentation process. Just as in the previous method of calculating UIQ, each task is made up of a series of sub tasks. These sub tasks are indicated in the task graph of previous section. Each one of these sub tasks indicates an exchange of information between the user interface software and the human operator. When human operator enters some data into the system, there is a certain amount of difficulty entering this information into the smart phone gadget. When smart phone displays something to the human operator, again there is certain amount of difficulty grasping this information from the screen of the smart phone gadget. These difficulty levels were indicated as *Cmh* and *Chm* in the previous section and are calculated in an objective manner by observing the amount of time it takes for the human operator to enter or grasp the information. Together with the number of interactions necessary for completing a given task, this whole system indicates the "intelligence" of the smart phone operating system.

The fuzzy logic system is adjusted in such a way that the number of interactions, the difficulty of grasping information from the smart phone screen, and the difficulty of entering information to the smart phone gadget are all considered in determination of the intelligence value, UIQ, with a series of if-then rules. This is the same mechanism people use while assessing the intelligence of an operating system.

The fuzzy logic rules and the variables used for calculation of UIQ for each task is given in the following sections.

5.2.1. "Make a Call" Task

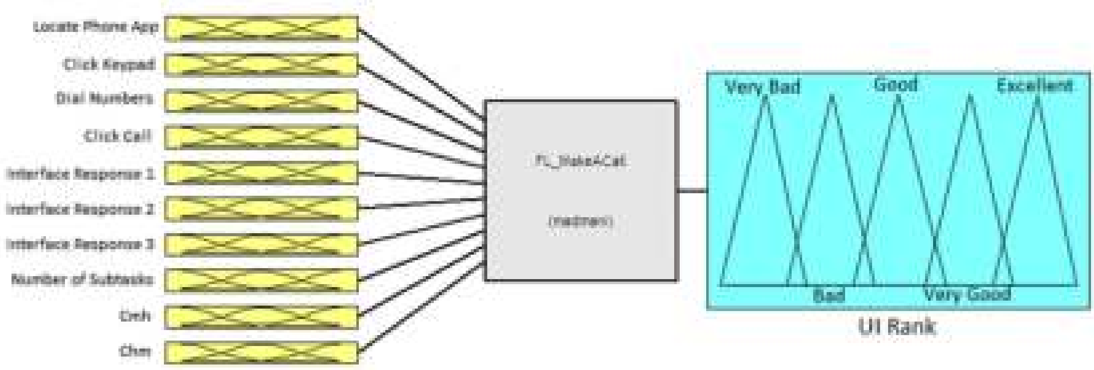

Figure 38. FIS for the "make a call" task.

The following are the Matlab commands for calculating the UIQ for the five smartphones:

```
>> fuzzy FL_MakeACall
>> MakeACall = readfis('FL_MakeACall.fis')

MakeACall =
```

```
        name: 'FL_MakeACall'
        type: 'mamdani'
        andMethod: 'min'
        orMethod: 'max'
        defuzzMethod: 'centroid'
        impMethod: 'min'
        aggMethod: 'max'
        input: [1x10 struct]
        output: [1x1 struct]
        rule: [1x15 struct]

>> OS1_MakeACall_UIQ =
evalfis([6.22;0;9.3;0.3;2.01;0;2.89;5;0.05;0.039],MakeACall)

OS1_MakeACall_UIQ =
  52.9761

>> OS2_MakeACall_UIQ = evalfis([3.6;0;9.2;0.6;1.01;0;0.97;5;0.18;0.022],MakeACall)

OS2_MakeACall_UIQ =
  59.3466

>> OS3_MakeACall_UIQ = evalfis([3.2;0;9.4;0.3;0.7;0;0.1;5;0.032;0.029],MakeACall)

OS3_MakeACall_UIQ =
  84.8494

>> OS4_MakeACall_UIQ = evalfis([1.7;0;10.3;0.2;0.5;0;0.1;5;0.038;0.02],MakeACall)

OS4_MakeACall_UIQ =
  85.8027

>> OS5_MakeACall_UIQ =
evalfis([4;8.3;9.5;0.1;0.09;0.1;0.11;7;0.047;0.018],MakeACall)

OS5_MakeACall_UIQ =
  40.3058
```

5.2.2. "Send a Message" Task

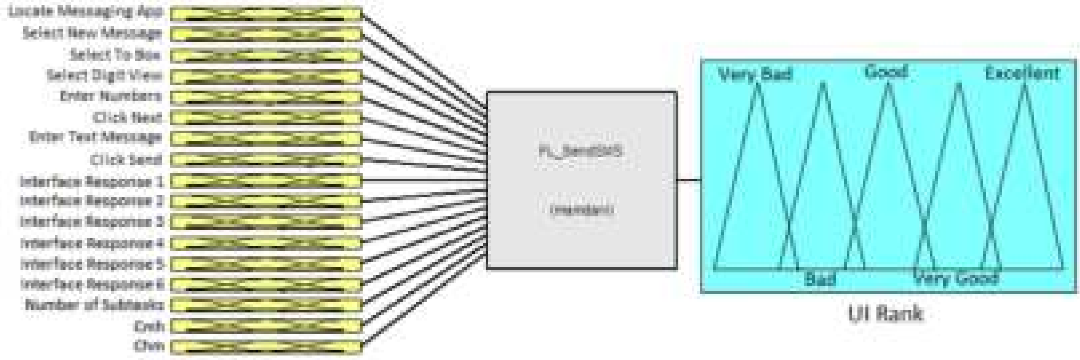

Figure 39. FIS for the "send a message" task.

The following are the Matlab commands for calculating the UIQ for the five smartphones:

```
>> fuzzy FL_SendSMS
>> SendSMS = readfis('FL_SendSMS.fis')

SendSMS =
        name: 'FL_SendSMS'
        type: 'mamdani'
        andMethod: 'min'
        orMethod: 'max'
        defuzzMethod: 'centroid'
        impMethod: 'min'
        aggMethod: 'max'
        input: [1x17 struct]
        output: [1x1 struct]
        rule: [1x15 struct]

>> OS1_SendSMS_UIQ =
evalfis([3.6;0.7;0.4;4.2;12.8;1.2;62.9;2;2.07;1.1;1.1;0.1;2.04;1;14;0.05;0.039],SendSMS)

OS1_SendSMS_UIQ =
  34.0478

>> OS2_SendSMS_UIQ =
evalfis([8.9;2.1;0;4.6;12.5;3.6;46.7;1.4;1.04;0.17;0;0.04;0.1;0.25;12;0.18;0.022],SendSMS)

OS2_SendSMS_UIQ =
```

53.0629

>> OS3_SendSMS_UIQ =
evalfis([2.67;2.89;0;2.56;8.7;5.4;36.7;1.4;0.6;0.98;0;0.03;0.04;0.23;12;0.032;0.029],SendSMS)

OS3_SendSMS_UIQ =
84.8494

>> OS4_SendSMS_UIQ =
evalfis([5.1;2.4;0;5.1;12.3;3.2;33.4;1.1;0.5;0.1;0;0.02;0.04;0.1;12;0.038;0.02],SendSMS)

OS4_SendSMS_UIQ =
85.8027

>> OS5_SendSMS_UIQ =
evalfis([1.9;3;0;2.7;8.7;1;40;7.3;0.09;0.1;0;0.2;0.04;0.08;12;0.047;0.018],SendSMS)

OS5_SendSMS_UIQ =
83.2607

5.2.3. "Make Appointment" Task

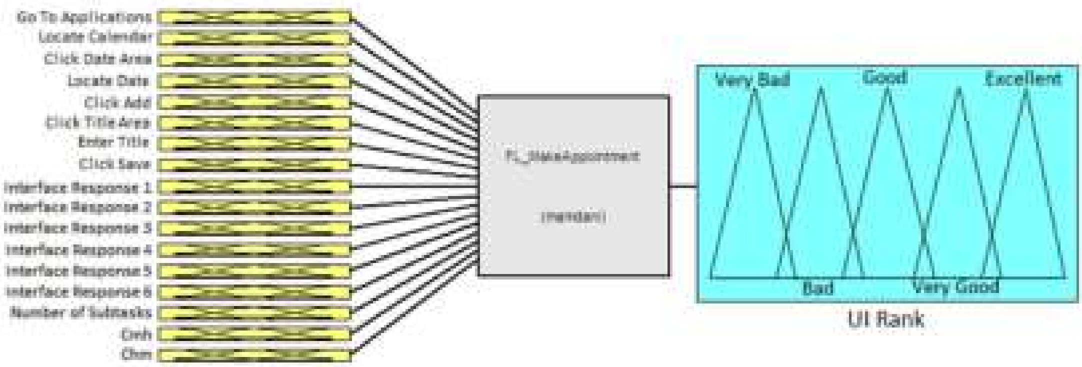

Figure 40. FIS for "make appointment" task.

The following are the Matlab commands for calculating the UIQ for the five smartphones:

>> fuzzy FL_MakeAppointment
>> MakeAppointment = readfis('FL_MakeAppointment.fis')

MakeAppointment =

```
name: 'FL_MakeAppointment'
type: 'mamdani'
andMethod: 'min'
orMethod: 'max'
defuzzMethod: 'centroid'
impMethod: 'min'
aggMethod: 'max'
input: [1x17 struct]
output: [1x1 struct]
rule: [1x15 struct]

>> OS1_MakeAppointment_UIQ =
evalfis([50.7;2.4;0;5.5;0;1.9;5.9;1.9;0.2;1.01;1.02;0.1;0.21;0;11;0.05;0.039],MakeAppointment)

OS1_MakeAppointment_UIQ =
  48.9743

>> OS2_MakeAppointment_UIQ =
evalfis([50.7;2.4;0;5.5;0;1.9;5.9;1.9;0.2;1.01;1.02;0.1;0.21;0;11;0.18;0.022],MakeAppointment)

OS2_MakeAppointment_UIQ =
  52.6386

>> OS3_MakeAppointment_UIQ =
evalfis([0;5.3;0;8.7;4.6;4;7.1;2.1;1.02;1.18;1.02;0.23;0.18;0;12;0.032;0.029],MakeAppointment)

OS3_MakeAppointment_UIQ =
  82.0867

>> OS4_MakeAppointment_UIQ =
evalfis([0;3.78;0;6.75;5;0;8.67;2.67;0.5;1.1;0.1;0;0;0;8;0.038;0.02],MakeAppointment)

OS4_MakeAppointment_UIQ =
  85.8027
```

```
>> OS5_MakeAppointment_UIQ =
evalfis([0;9.11;1.88;12.57;2.78;1.67;5.56;2.33;0.09;0.08;0.03;0.1;0.03;0.05;14;0.047;
0.018],MakeAppointment)

OS5_MakeAppointment_UIQ =
  38.8544
```

5.2.4. "Go to Webpage" Task

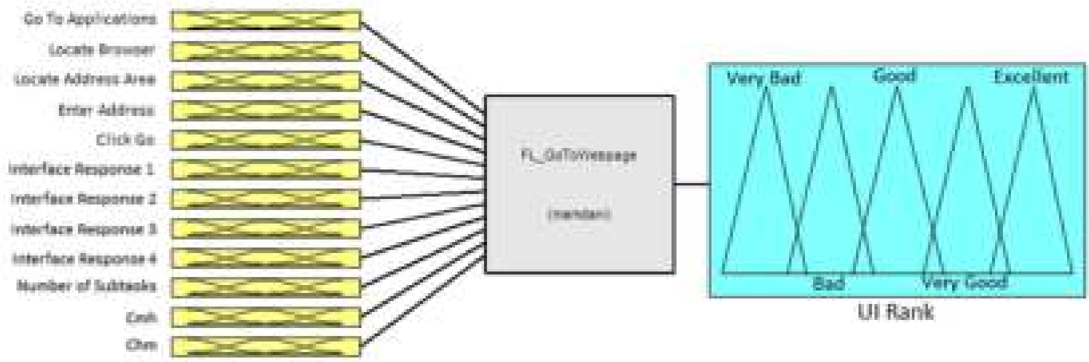

Figure 41. FIS for "go to webpage" task.

The following are the Matlab commands for calculating the UIQ for the five smartphones:

```
>> fuzzy FL_GoToWebpage
>> GoToWebpage = readfis('FL_GoToWebPage.fis')

GoToWebpage =
        name: 'FL_GoToWebpage'
        type: 'mamdani'
        andMethod: 'min'
        orMethod: 'max'
        defuzzMethod: 'centroid'
        impMethod: 'min'
        aggMethod: 'max'
        input: [1x12 struct]
        output: [1x1 struct]
        rule: [1x15 struct]

>> OS1_GoToWebpage_UIQ =
evalfis([0;3.89;2.4;16.2;0.7;0;1.89;1.02;2.99;7;0.05;0.039],GoToWebpage)

OS1_GoToWebpage_UIQ =
  58.6493
```

```
>> OS2_GoToWebpage_UIQ =
evalfis([6.875;2.375;1.125;9.875;0.875;0.2;1.1;1.1;0.2;9;0.18;0.022],GoToWebpage)

OS2_GoToWebpage_UIQ =
  29.1598

>> OS3_GoToWebpage_UIQ =
evalfis([0;1.667;2;11.7;1.1;0;0.22;0.12;0.3;7;0.032;0.029],GoToWebpage)

OS3_GoToWebpage_UIQ =
  84.2732

>> OS4_GoToWebpage_UIQ =
evalfis([0;4.6;0.7;7.9;0.9;0;0.11;0.09;0.1;7;0.038;0.02],GoToWebpage)

OS4_GoToWebpage_UIQ =
  64.4024

>> OS5_GoToWebpage_UIQ =
evalfis([0;3.8;2.4;8.3;2.9;0;0.09;0.04;0.11;7;0.047;0.018],GoToWebpage)

OS5_GoToWebpage_UIQ =
  83.0060
```

Chapter 6: Discussion of Results

6.1. UIQ Metric Results

After applying the UIQ metric on the data collected from the experiments, the UIQ rate for each of the tasks on each smartphone is shown in Figure 42.

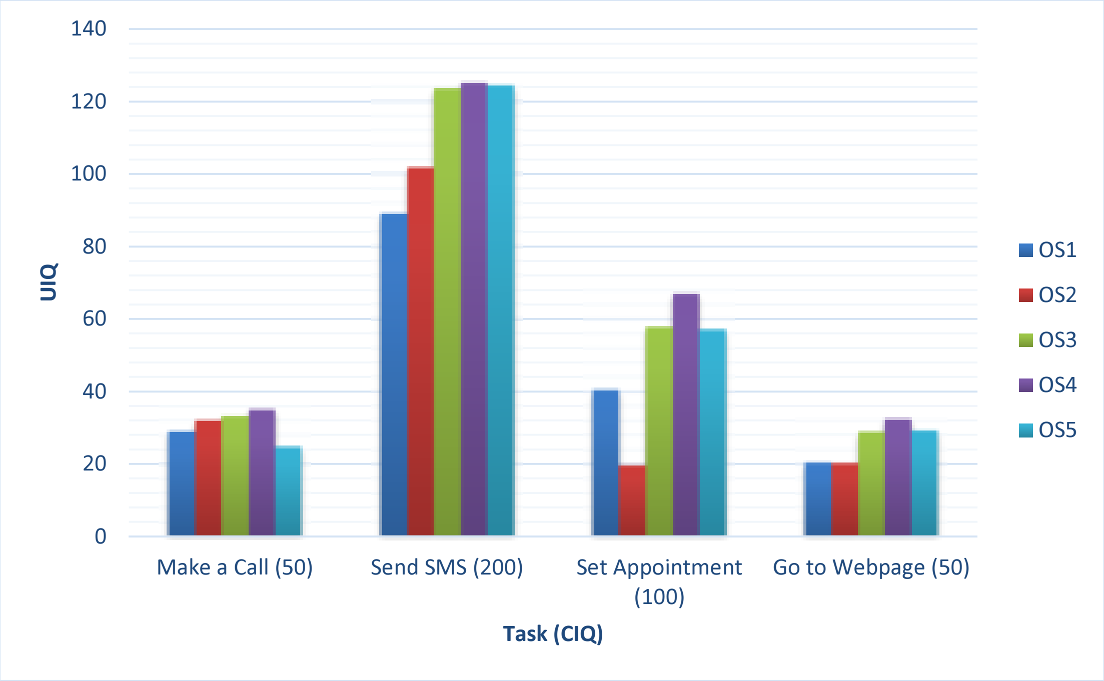

Figure 42. Results from UIQ Metric.

These results are calculated in purely objective manner through the data collected during the experiments. Each group indicates the relative intelligence of the operating systems. A higher index value indicates higher UIQ, which means a user interface which is easier to use by the human operator.

6.2. Fuzzy Logic Results

The same data collected from the experiments was fed into the different FISs that were developed for each task. After repeating the process for each smartphone, the UIQ results were as seen below in Figure 43.

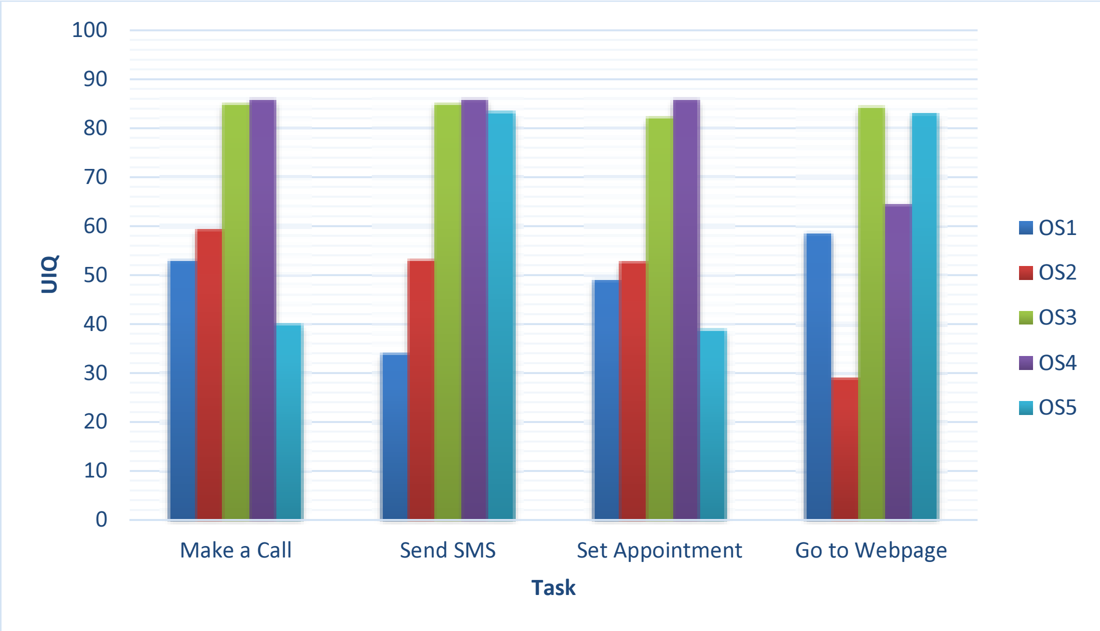

Figure 43. Results from Fuzzy Logic System.

The results shown in figure 43 indicate the relative intelligence value, UIQ, of the operating systems as determined by a fuzzy logic system. The values acquired during the experiments were utilized for calculation of these results. The results should be interpreted as a relative measure between different operating systems. Each task group should be considered as separate with no relations between different groups.

6.3. Survey Results

In order to evaluate these results and see if they corroborate with the public, the results from the metric have been compared with the results from the survey taken by the users after they used the smartphones. Since the totals that are added up have a higher value for higher complexity, the inverse of the totals is used so that the larger the result, the easier it is to complete a task (this corresponds to a smarter UI). The results from the survey have been re-plotted on a bar graph which is shown in Figure 44.

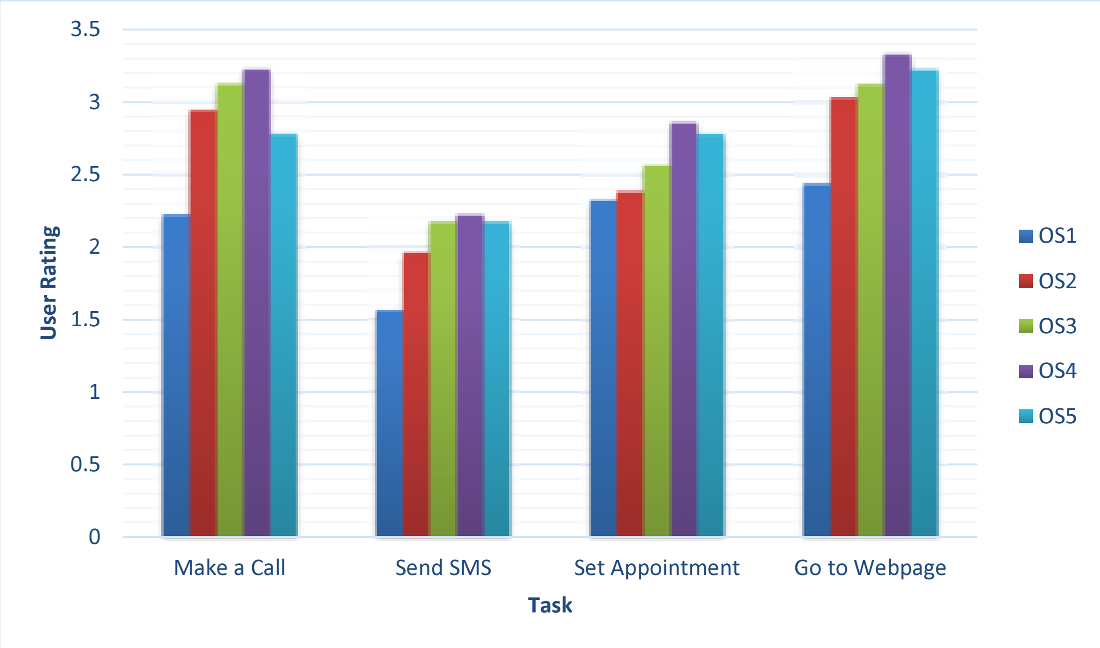

Figure 44. Results from survey.

6.4. Comparison and Evaluation the Results

Figures 42, 43, and 44 show the results from the developed metric, fuzzy logic, and the survey. Apart from very few exceptions, these graphs are almost similar in shape. The results show that the metric developed can be used to predict users' perceptions of the UI.

Figure 42 uses the data gathered in an objective manner through the experiments. The data is calculated through a fixed regiment similar to calculation of MIQ.

Figure 43 uses the same data gathered in an objective manner through the experiments and calculates the UIQ in a way a human being decides.

Figure 44 shows the actual survey results from the human users. Obviously these values are quite subjective and reflect the decision-making process of human operators.

The fuzzy logic results shown in Figure 43 may not be similar to Figure 44 but by properly reverse engineering the fuzzy decision rules, the results may reflect the decision process of human operators with data gathered from the experiments.

According to these results, the data gathered objectively through experiments, coupled with fuzzy decision rules similar to the human operators, give reasonably accurate feedback about the intelligence level of operating systems.

The three graphs (Figures 42, 43, and 44) have displayed the level of "smartness" as calculated by the metric, fuzzy logic, and the user's survey. The smartphones are then going to be positioned in ranks from 1 to 5, 1 being the smartest. Table 23 shows these ranks by the three different methods. As seen, the ranks of most of the smartphones for the various functions are the same.

Table 23. Ranking of smartphones based on the three different results.

Task\OS		OS1	OS2	OS3	OS4	OS5
Make a Call	UIQ Metric	4	3	2	1	5
	Fuzzy Logic	4	3	2	1	5
	Survey	5	3	2	1	4
Send SMS	UIQ Metric	5	4	3	1	2
	Fuzzy Logic	5	4	2	1	3
	Survey	5	4	3	1	2
Set Appointment	UIQ Metric	4	5	2	1	3
	Fuzzy Logic	4	3	2	1	5
	Survey	5	4	3	1	2
Go to Webpage	UIQ Metric	4	5	3	1	2
	Fuzzy Logic	4	5	1	3	2
	Survey	5	4	3	1	2

When comparing between the UIQ metric and the survey results, Table 23 shows a perfect match for the smartphone ranked as the smartest. However, there is a tradeoff between ranks 2 and 3, and between 4 and 5. These differences still prove the working of the metric since there is a difference in only one position. This shows a 60% accuracy rate between the UIQ metric and the survey.

However, when comparing the fuzzy logic and the survey results, the table shows various errors even with the smartest phone ranked at 1, where FL gets the wrong result. This shows a 40% accuracy rate between fuzzy logic and the survey.

An interesting result, however, is the matching between the two methods used, the UIQ metric and fuzzy logic. The two methods got the same result 70% of the time which shows that the two methods are similar.

Chapter 7: Conclusion

The goal of this thesis has been to introduce a metric that can calculate the "usefulness" of a human-computer interface. The usefulness of the human-computer interface is commonly called "smartness" and becomes the center of attention with the proliferation of smart phones and smart machines. In today's aggressive smartphone market, user friendliness has been rated as one of the most important factors in winning customers. So far, user satisfaction about the "usefulness" of the human-machine interface has only been determined by user surveys. Although user surveys are the ultimate way of understanding the quality of the human-machine interface, an objective method of measurement, that is a metric, would be very useful for determining and measuring the performance of such systems. From this point of view, this thesis may prove to be very useful for smartphone manufacturers, who would be able to run a series of tests using this metric and finally get numerical results that indicate the performance of their system. In case the results are not as good as expected, they can come up with a different design before releasing the product to the public, hence saving a failure before it launches.

To the best of our knowledge there are no other objective methods that generate measurable metrics for "smartness" of the human-machine interface. In order to make sense out of the generated metric, the "smartness" metric is presented in three forms which are complementary to each other:

a) Basic UIQ measurements which generate raw metrics for smartness of processes,
b) Fuzzy logic system output which generates a derived metric based on the smartness of multiple processes,
c) User surveys which indicate the opinion of users in a classical manner.

User survey results are used for determining the fidelity of the results generated by the basic user interface intelligence quotient (UIQ) and fuzzy logic outputs.

Fuzzy logic was chosen as an alternative method of generating a metric since verbal description of the quality of a user interface has always been in words such as "good" and "bad," which is what fuzzy logic mainly deals with. Moreover, fuzzy logic makes it easy to take the experiment another step further by calculating the user interface intelligence quotient only for a specific type of use.

The results showed that the UIQ metric and the fuzzy logic metric generated results that matched 70% of the times. The survey results indicated that UIQ and fuzzy logic results have been within the ballpark, indicating that they are relationally correct. However, differences in actual values indicated that there is room for fine tuning of the membership functions of the fuzzy logic system.

As an explanation of the above process, the results for one of the tasks, the "Send SMS" task, is shown below (Figure 45).

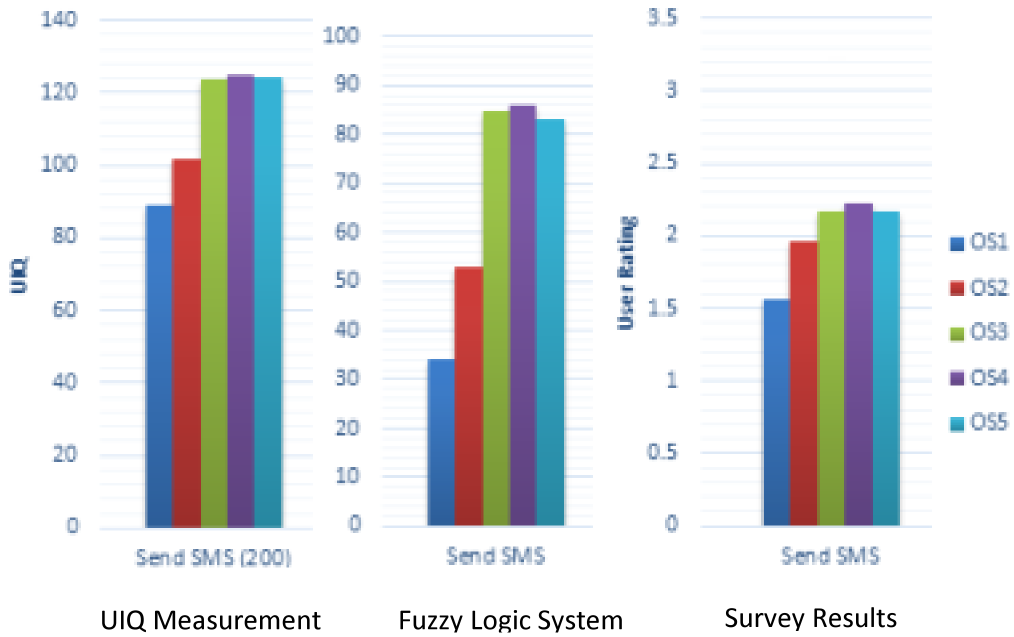

Figure 45. Values generated for the task of "Send SMS" function.

As can be seen from the figure, the relative relationship evaluation for different operating systems is consistent with all three evaluations. Survey results indicated that users found the fourth operating system, OS4, as the "smartest" interface which is easiest to use. OS3 is ranked as the second "smartest", followed by OS5, OS2 and OS1.

The UIQ calculations revealed measurement results which are very consistent with the survey results. UIQ results should be treated as unit-less values that give relative "smartness" values with respect to different systems that are evaluated. In this case, UIQ measurements give exactly the same ranking as the survey results, ranking OS4, OS3, OS5, OS2 and OS1. It is interesting to notice that the relative gap in "smartness" of different operating systems, like the difference between OS1 and OS2 found in the survey, is correctly reflected in UIQ evaluations.

The fuzzy inference systems results for the "Send SMS" task are also very much in line with both the UIQ and survey results. Just like the UIQ and survey ranking, the fuzzy inference system ranking also rates OS4 as the highest "smartness" value followed by OS3, OS5, OS2 and OS1. Since the fuzzy inference system works based on raw UIQ results, that result should be expected. The fuzzy inference system, however, let us tailor the system to reveal results very much similar to the survey results. The fuzzy inference system parameters like membership functions and fuzzy rules can be tuned to give results closer to human responses. In this particular case, the fuzzy inference system revealed values which are consistent with both survey and UIQ results.

7.1. Difficulties Faced

There were some difficulties that were faced while conducting experiments as well as calculating the results. The major difficulty was getting volunteers to participate in the experiments. The tasks that were assigned to each user took an average of forty minutes to complete, so it was difficult to find volunteers willing to participate. Moreover, the users were taken to a familiar environment to avoid them feeling uncomfortable while conducting the experiments which could affect the results; this added to the difficulty of getting more volunteers.

In addition, the fuzzy logic rules in the fuzzy logic system were calculated to total more than 17 thousand. As a result, an assumption was made to choose the most important rules only in order to save time and make the test more efficient.

7.2. Future Work

A factor that was not considered and could have improved the results is the users' familiarity with certain smartphone user interfaces. This familiarity could cause the user to interpret that particular user interface as the easiest to use and hence the smartest. In order to improve the results, familiarity should be considered. Users should not be expected to give a fair result if they are assigned to test an interface which they are familiar to.

An assumption that was made that could have affected the results is the reduction of the fuzzy logic rules. Results of the fuzzy logic metric could be improved in the future by accounting for all the rules of the fuzzy logic system.

Another factor that could have affected the results is the small number of participants. Hence in future work the same tests can be made on a larger number of participants. This can greatly increase the accuracy and more importantly the reliability of the results obtained by the developed metric.

Finally, a useful addition for conducting these experiments can be an eye tracking device which detects where the users are looking while testing the phones. This addition is not expected to increase the accuracy of results; however, it can be used by user interface designers to recognize which areas the users are looking at when stuck in completing a task. This would help the designers understand how to improve their user interface to avoid cases where the users can’t find what they are looking for.

7.3. Use in Real World

This metric can be used as a means of measurement where it can be monitored by an international organization, where for each release of a new smartphone, a UIQ number could be embedded with it. The user would start getting familiar with the UIQ as a specification of smartphones, knowing that the higher the number is, the easier the UI will be – and this can influence buying decisions. Moreover, there can be different UIQs for each smartphone depending on the intended use of the smartphone. For instance, a smartphone’s UIQ could be high for basic use but could decrease when it comes to advanced use.

Finally, smartphone manufacturers can make use of this metric by calculating the results for their old user interface and comparing these results to the results of their new user interface, making sure that the numbers are better for their updated user interface. This way, they can continuously improve the quality of the user interface.

To sum up, there is great room for improvement of the UIQ metric and its use in the real world can prove to be invaluable. If the UIQ metric is implemented, it could change the approach of consumers when selecting their new smartphone, which could eventually make an impact on the market share of smartphones.

Preliminary results of this study are published in following journals and conferences:

El Zarka, Ahmed, and Tarik Ozkul. "Assessment Metrics for Intelligence Level of Human-Computer Interface." Journal of Emerging Trends in Computing and Information Sciences 4, no. 3 pp. 319-352.

El Zarka, Ahmed, and Tarik Ozkul. "Assessment Metrics for Intelligence Level of Human-Computer Interface." In Proceedings of the IEEE International Conference on Computer Systems and Industrial Informatics – ICCSII'12, Sharjah UAE Dec. 18-20, 2012.

Ozkul, Tarik, and El Zarka, Ahmed. "A New Model for Measuring Human-Smart Machine Interface Quality." In The Proceedings of 2nd International Conference on Automatic Control, Soft Computing and Human-Machine Interaction (ASME '13) pp. 191-196 April 23-25 2013, Marioka, Japan.

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Appendix A

This appendix includes the experiment scenario and survey form that was handed to all participants.

Thank you for participating in the following study:
Development of Quantitative Assessment Metrics for Determining the Intelligence Level of a Human-Computer Interface

Completed in accordance with the completion of Master's Thesis work COE699 by **Ahmed El Zarka**

In this experiment you will be asked to complete a series of tasks using various mobile phones.

A video recording will be taken of the whole experiment.

Firstly please mark the mobile operating systems that you are familiar with:

- iOS (iPhone)
- Android (Samsung, Huawei)
- Windows 7 (HTC, Nokia Lumia)

Please pick up the first phone and complete the following tasks:

1. Call the following number: 056 7466405
2. Send an SMS containing the following text: "Hi sorry I will be 5 minutes late!" to 056 7466405
3. Set an appointment on the calendar on your birthday
4. Connect with Wi-Fi to the AUS_Wireless network (User name and Password already set on phone)
5. Open www.aus.edu on the phone's browser
6. Disconnect from the Wi-Fi network

Please pick up the next phone and complete the same tasks again.

After completing all the tasks with all the phones, you will have a final exercise to complete.
Pick up each phone again and with each one of them lock and unlock the phone as many times as possible within 30 seconds (time will be kept by the invigilator).

Thank you for your patience.
Name of Participant: ____________________________
Signature: ____________________________

First phone:

1. Call the following number: 056 7466405

Step	Easy	Medium	Difficult	Complex
1. Unlock phone				
2. Go to Phone application				
3. Enter the numbers				
4. Call				

2. Send an SMS containing the following text: "Hi sorry I will be 5 minutes late!"

Step	Easy	Medium	Difficult	Complex
1. Unlock phone				
2. Go to Messages application				
3. Enter the message				
4. Enter number to send to				
5. Send				

3. Set an appointment on the calendar on your birthday

Step	Easy	Medium	Difficult	Complex
1. Unlock phone				
2. Go to Calendar application				
3. Locate your birthday				
4. Set an appointment				

4. Connect with Wi-Fi to the AUS_Guest network

Step	Easy	Medium	Difficult	Complex
1. Unlock phone				
2. Go to Wi-Fi settings				
3. Connect to Wi-Fi				

5. Open www.aus.edu on the phone's browser

Step	Easy	Medium	Difficult	Complex
1. Unlock phone				
2. Go to Browser application				
3. Enter Website Address				
4. Click on Go				

6. Disconnect from the Wi-Fi network

Step	Easy	Medium	Difficult	Complex
1. Unlock phone				
2. Go to Wi-Fi settings				
3. Disconnect from Wi-Fi				

Second phone:

1. Call the following number: 056 7466405

Step	Easy	Medium	Difficult	Complex
1. Unlock phone				
2. Go to Phone application				
3. Enter the numbers				
4. Call				

2. Send an SMS containing the following text: “Hi sorry I will be 5 minutes late!”

Step	Easy	Medium	Difficult	Complex
1. Unlock phone				
2. Go to Messages application				
3. Enter the message				
4. Enter number to send to				
5. Send				

3. Set an appointment on the calendar on your birthday

Step	Easy	Medium	Difficult	Complex
1. Unlock phone				
2. Go to Calendar application				
3. Locate your birthday				
4. Set an appointment				

4. Connect with Wi-Fi to the AUS_Guest network

Step	Easy	Medium	Difficult	Complex
1. Unlock phone				
2. Go to Wi-Fi settings				
3. Connect to Wi-Fi				

5. Open www.aus.edu on the phone’s browser

Step	Easy	Medium	Difficult	Complex
1. Unlock phone				
2. Go to Browser application				
3. Enter Website Address				
4. Click on Go				

6. Disconnect from the Wi-Fi network

Step	Easy	Medium	Difficult	Complex
1. Unlock phone				
2. Go to Wi-Fi settings				
3. Disconnect from Wi-Fi				

Third phone:

1. Call the following number: 056 7466405

Step	**Easy**	**Medium**	**Difficult**	**Complex**
1. Unlock phone				
2. Go to Phone application				
3. Enter the numbers				
4. Call				

2. Send an SMS containing the following text: "Hi sorry I will be 5 minutes late!"

Step	**Easy**	**Medium**	**Difficult**	**Complex**
1. Unlock phone				
2. Go to Messages application				
3. Enter the message				
4. Enter number to send to				
5. Send				

3. Set an appointment on the calendar on your birthday

Step	**Easy**	**Medium**	**Difficult**	**Complex**
1. Unlock phone				
2. Go to Calendar application				
3. Locate your birthday				
4. Set an appointment				

4. Connect with Wi-Fi to the AUS_Guest network

Step	**Easy**	**Medium**	**Difficult**	**Complex**
1. Unlock phone				
2. Go to Wi-Fi settings				
3. Connect to Wi-Fi				

5. Open www.aus.edu on the phone's browser

Step	**Easy**	**Medium**	**Difficult**	**Complex**
1. Unlock phone				
2. Go to Browser application				
3. Enter Website Address				
4. Click on Go				

6. Disconnect from the Wi-Fi network

Step	**Easy**	**Medium**	**Difficult**	**Complex**
1. Unlock phone				
2. Go to Wi-Fi settings				
3. Disconnect from Wi-Fi				

Fourth phone:

1. Call the following number: 056 7466405

Step	Easy	Medium	Difficult	Complex
1. Unlock phone				
2. Go to Phone application				
3. Enter the numbers				
4. Call				

2. Send an SMS containing the following text: “Hi sorry I will be 5 minutes late!”

Step	Easy	Medium	Difficult	Complex
1. Unlock phone				
2. Go to Messages application				
3. Enter the message				
4. Enter number to send to				
5. Send				

3. Set an appointment on the calendar on your birthday

Step	Easy	Medium	Difficult	Complex
1. Unlock phone				
2. Go to Calendar application				
3. Locate your birthday				
4. Set an appointment				

4. Connect with Wi-Fi to the AUS_Guest network

Step	Easy	Medium	Difficult	Complex
1. Unlock phone				
2. Go to Wi-Fi settings				
3. Connect to Wi-Fi				

5. Open www.aus.edu on the phone’s browser

Step	Easy	Medium	Difficult	Complex
1. Unlock phone				
2. Go to Browser application				
3. Enter Website Address				
4. Click on Go				

6. Disconnect from the Wi-Fi network

Step	Easy	Medium	Difficult	Complex
1. Unlock phone				
2. Go to Wi-Fi settings				
3. Disconnect from Wi-Fi				

Fifth phone:

1. Call the following number: 056 7466405

Step	Easy	Medium	Difficult	Complex
1. Unlock phone				
2. Go to Phone application				
3. Enter the numbers				
4. Call				

2. Send an SMS containing the following text: “Hi sorry I will be 5 minutes late!”

Step	Easy	Medium	Difficult	Complex
1. Unlock phone				
2. Go to Messages application				
3. Enter the message				
4. Enter number to send to				
5. Send				

3. Set an appointment on the calendar on your birthday

Step	Easy	Medium	Difficult	Complex
1. Unlock phone				
2. Go to Calendar application				
3. Locate your birthday				
4. Set an appointment				

4. Connect with Wi-Fi to the AUS_Guest network

Step	Easy	Medium	Difficult	Complex
1. Unlock phone				
2. Go to Wi-Fi settings				
3. Connect to Wi-Fi				

5. Open www.aus.edu on the phone’s browser

Step	Easy	Medium	Difficult	Complex
1. Unlock phone				
2. Go to Browser application				
3. Enter Website Address				
4. Click on Go				

6. Disconnect from the Wi-Fi network

Step	Easy	Medium	Difficult	Complex
1. Unlock phone				
2. Go to Wi-Fi settings				
3. Disconnect from Wi-Fi				

This will be filled out by the invigilator:

Lock and unlock phone as many times as possible in 30 seconds:

Phone used	**No. of times completed**
OS1	
OS2	
OS3	
OS4	
OS5	

Appendix B

This appendix includes all the task graphs for all the tasks on the five different smartphones.

Make a Call Task Graphs

This section includes all the task graphs for the "make a call" task for all the smartphone operating systems. The subtask number in the task graph is shown by a circle that contains **T**i where **i** is the number of the task in the function and a number which shows the complexity of the task. If the task is performed by the internal part of the user interface and the complexity is unknown, the complexity will be displayed as UI.

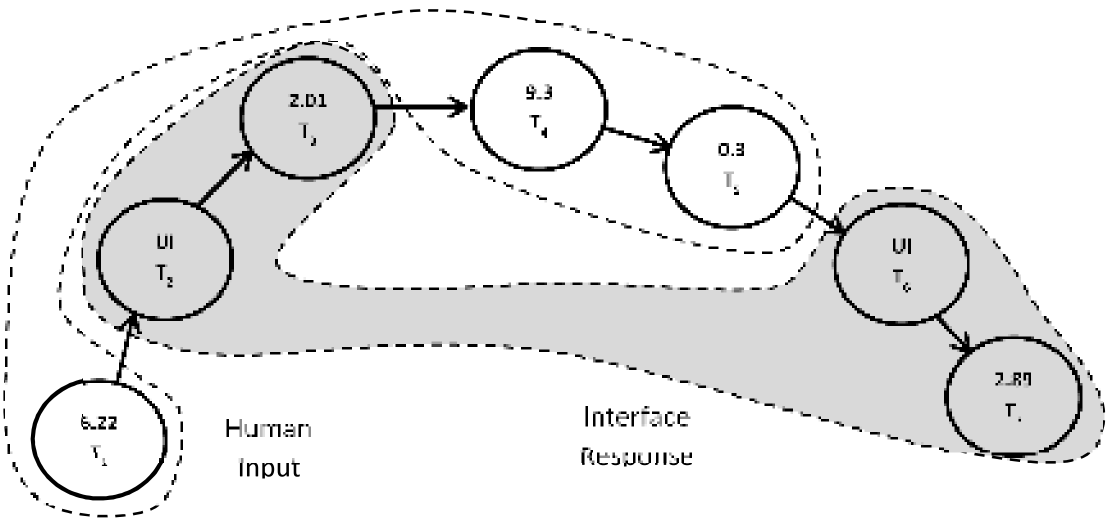

Figure 46. Task Graph for Make a call function on OS1.

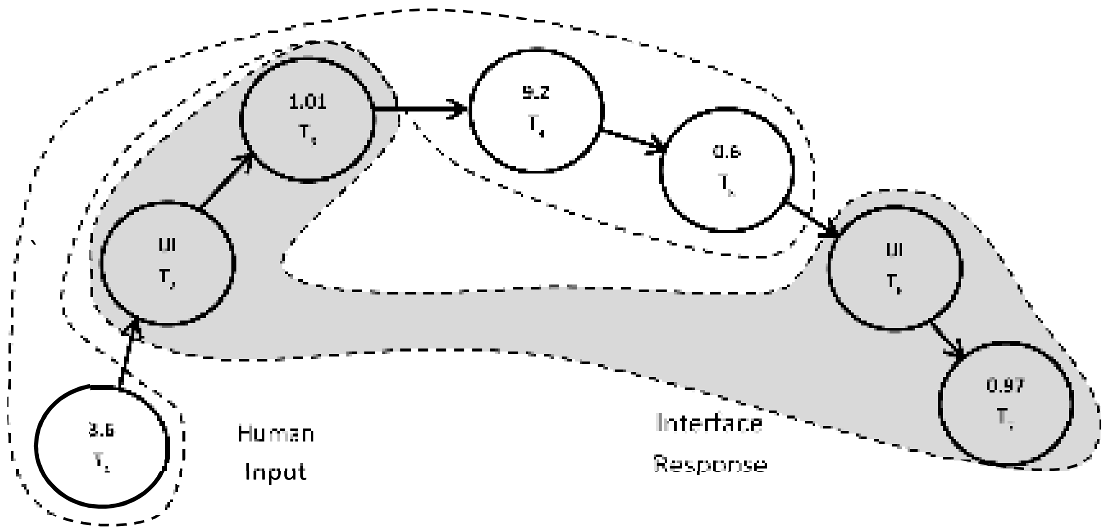

Figure 48. Task Graph for Make a Call Function on OS2.

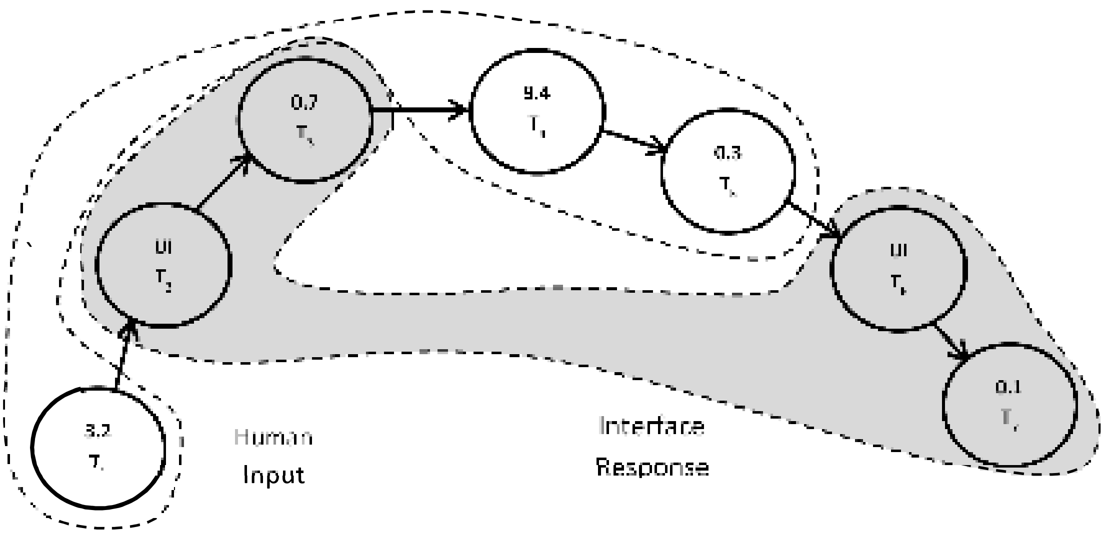

Figure 47. Task Graph for Make a Call function on OS3.

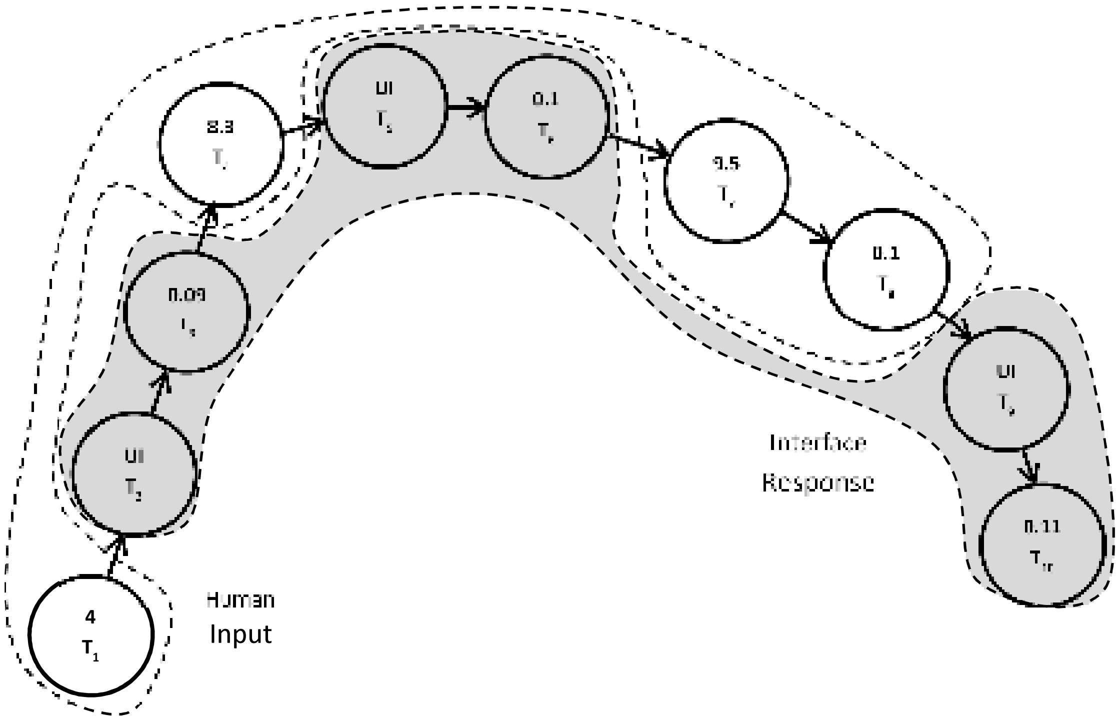

Figure 49. Task Graph for Make a Call function on OS5.

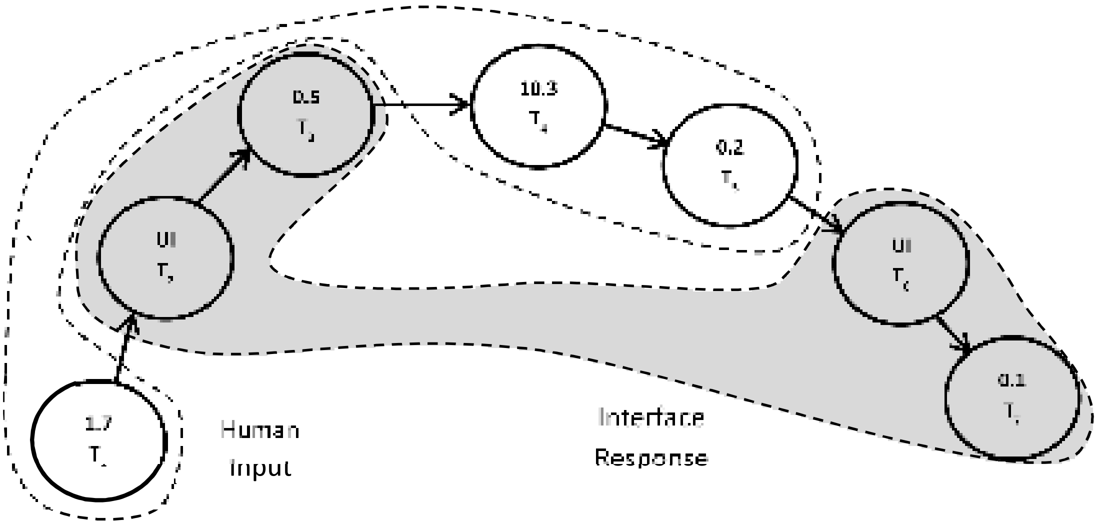

Figure 50. Task Graph for Make a Call function on OS4.

Figure 48 shows the task graph for the “make a call” function for OS5. A big difference can be seen between this task graph and the corresponding ones for the other smart phones. This is due to the increased number of tasks in this specific operating system for completing the same function.

Send SMS Task Graphs

This section includes the task graphs for the "send SMS" function for all the smartphone operating systems. The task number in the task graph is shown by a circle that contains Ti where i is the number of the task in the function and a number which shows the complexity of the task. If the task is performed by the internal part of the user interface and the complexity is unknown, the complexity will be displayed as UI.

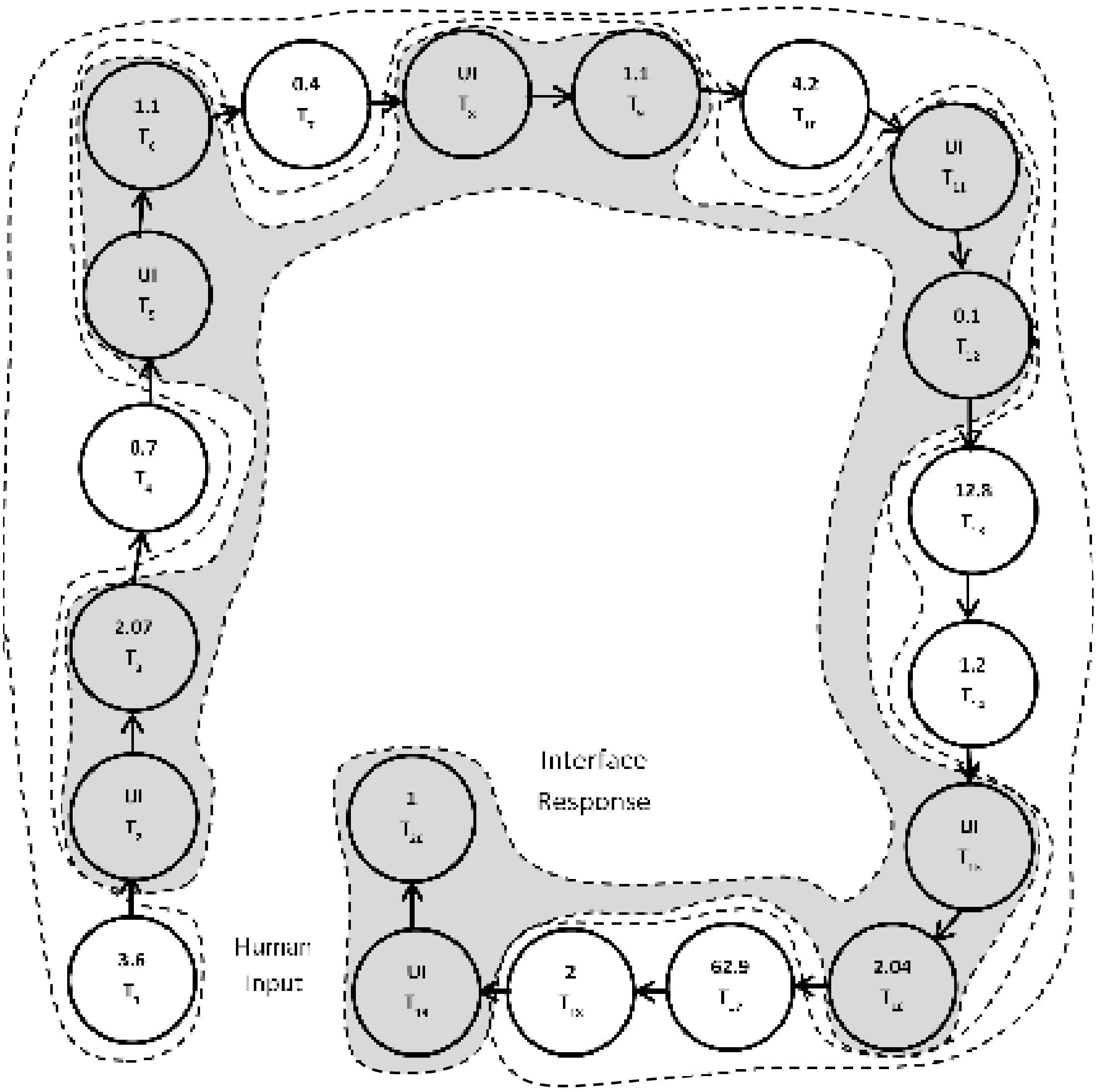

Figure 51. Task Graph for Send SMS function on OS1.

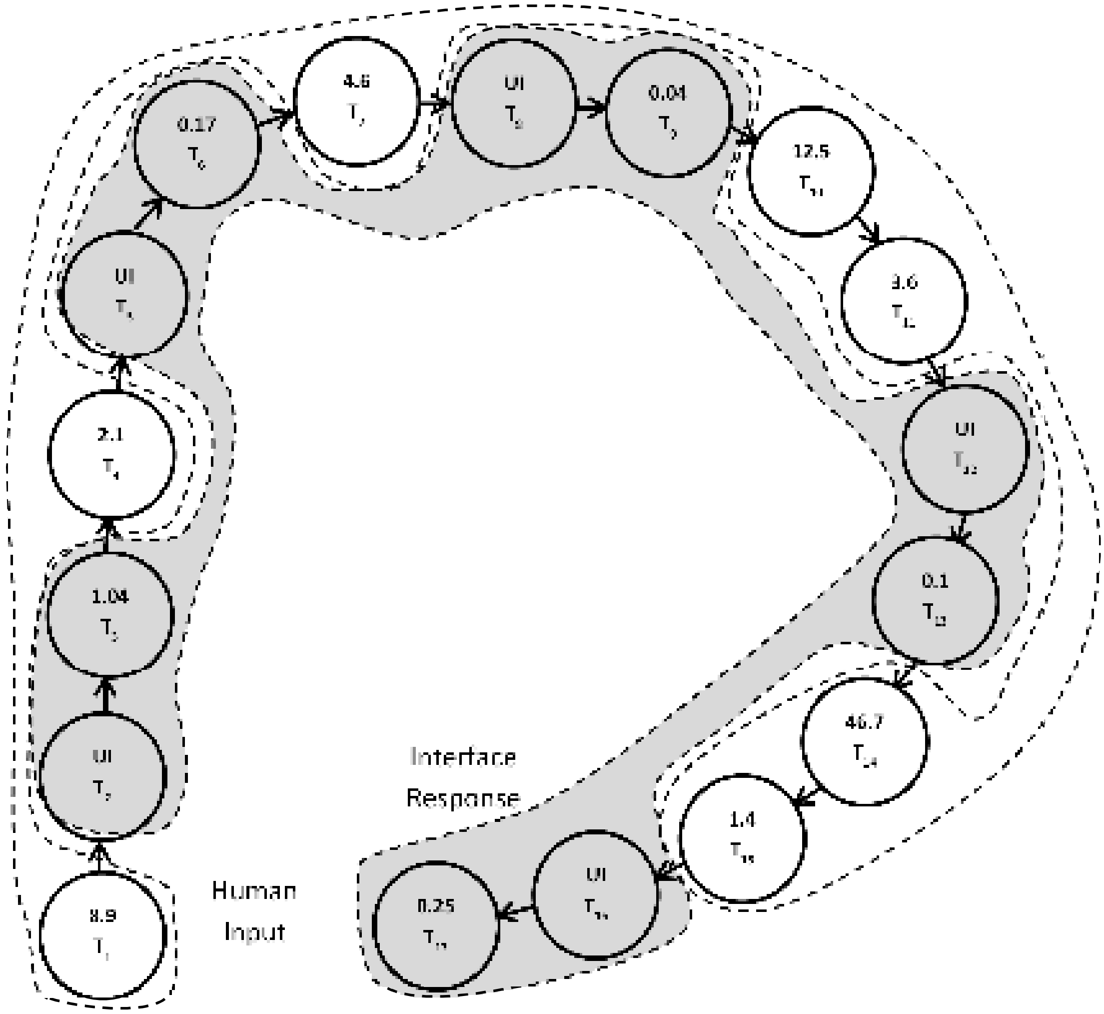

Figure 52. Task Graph for Send SMS function on OS2.

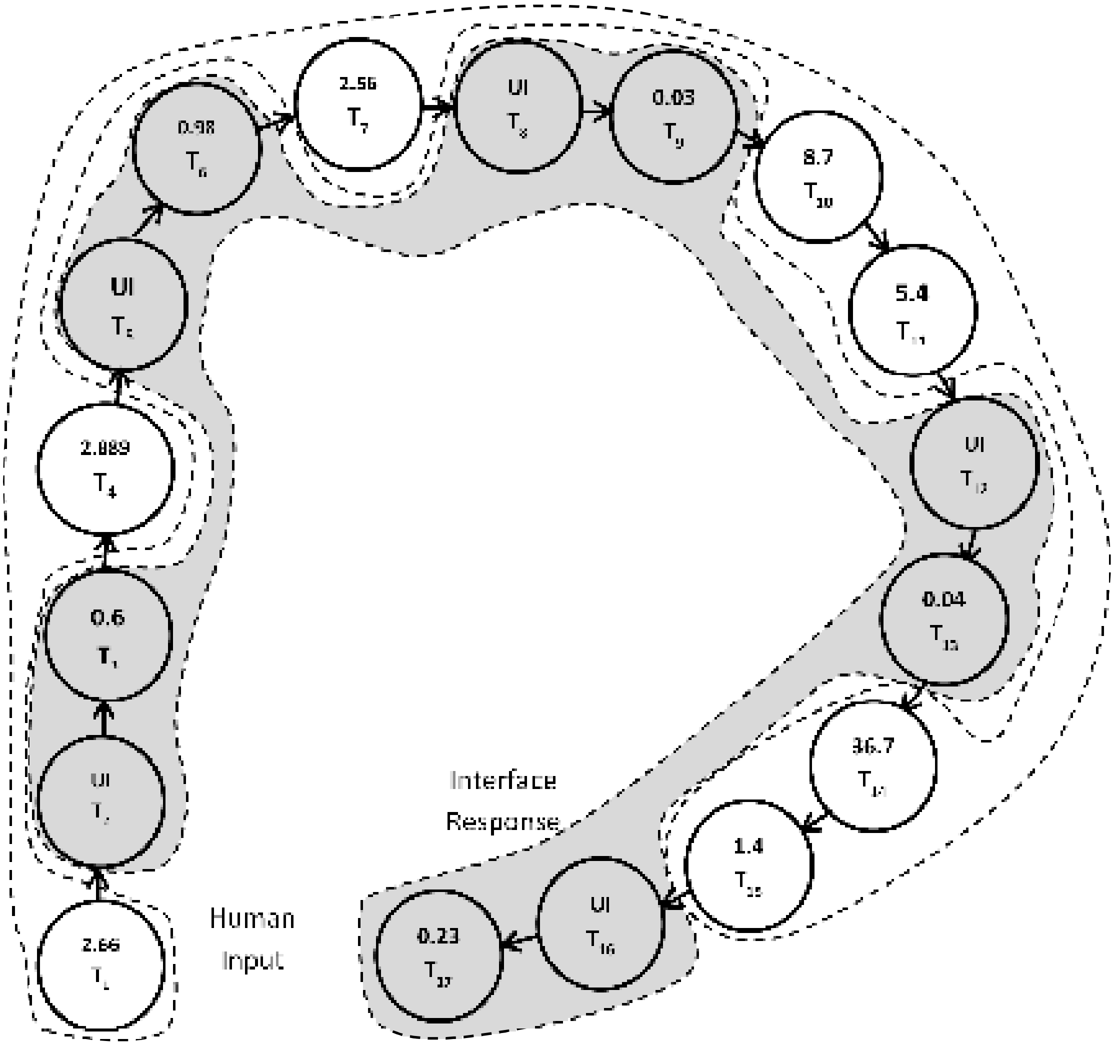

Figure 53. Task Graph for Send SMS function on OS3.

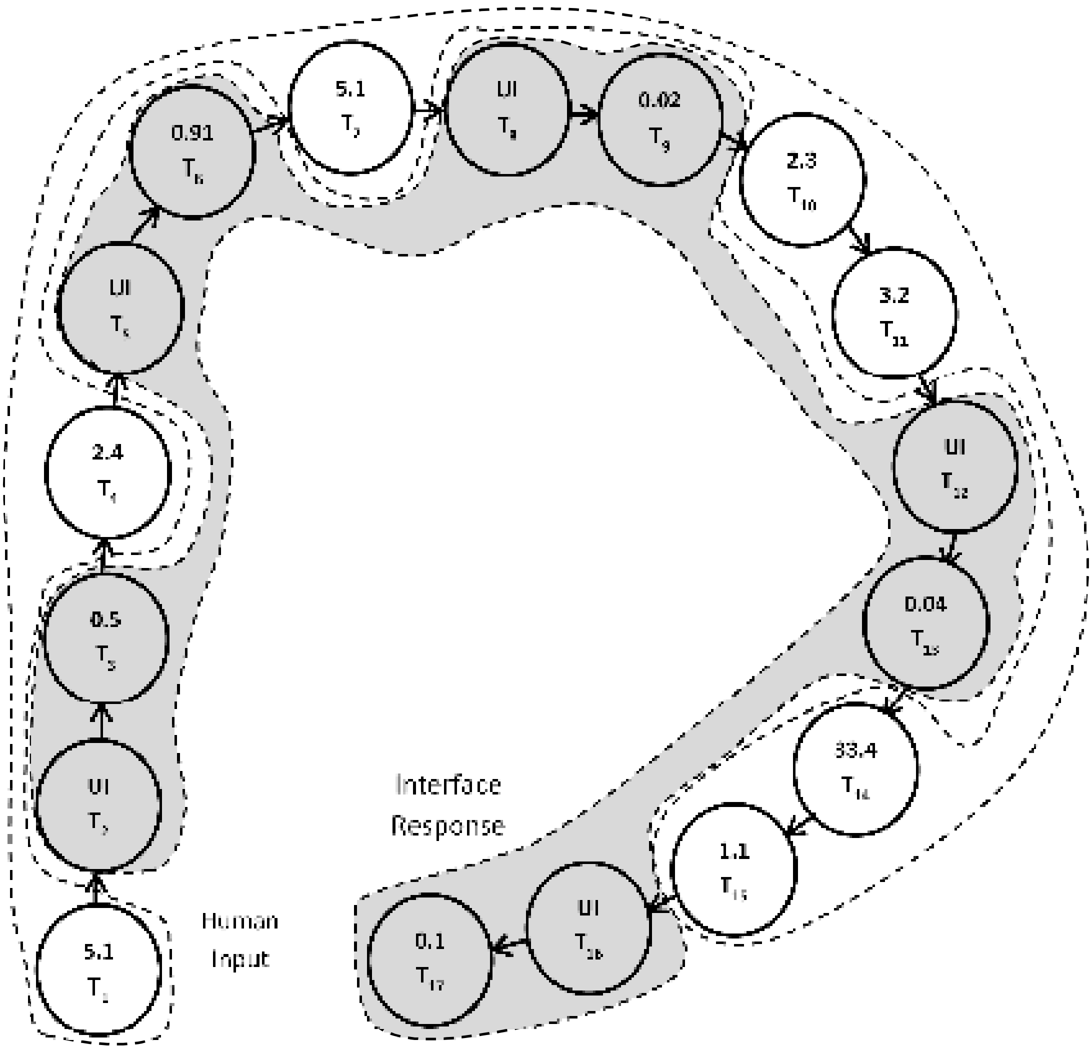

Figure 54. Task Graph for Send SMS function on OS4.

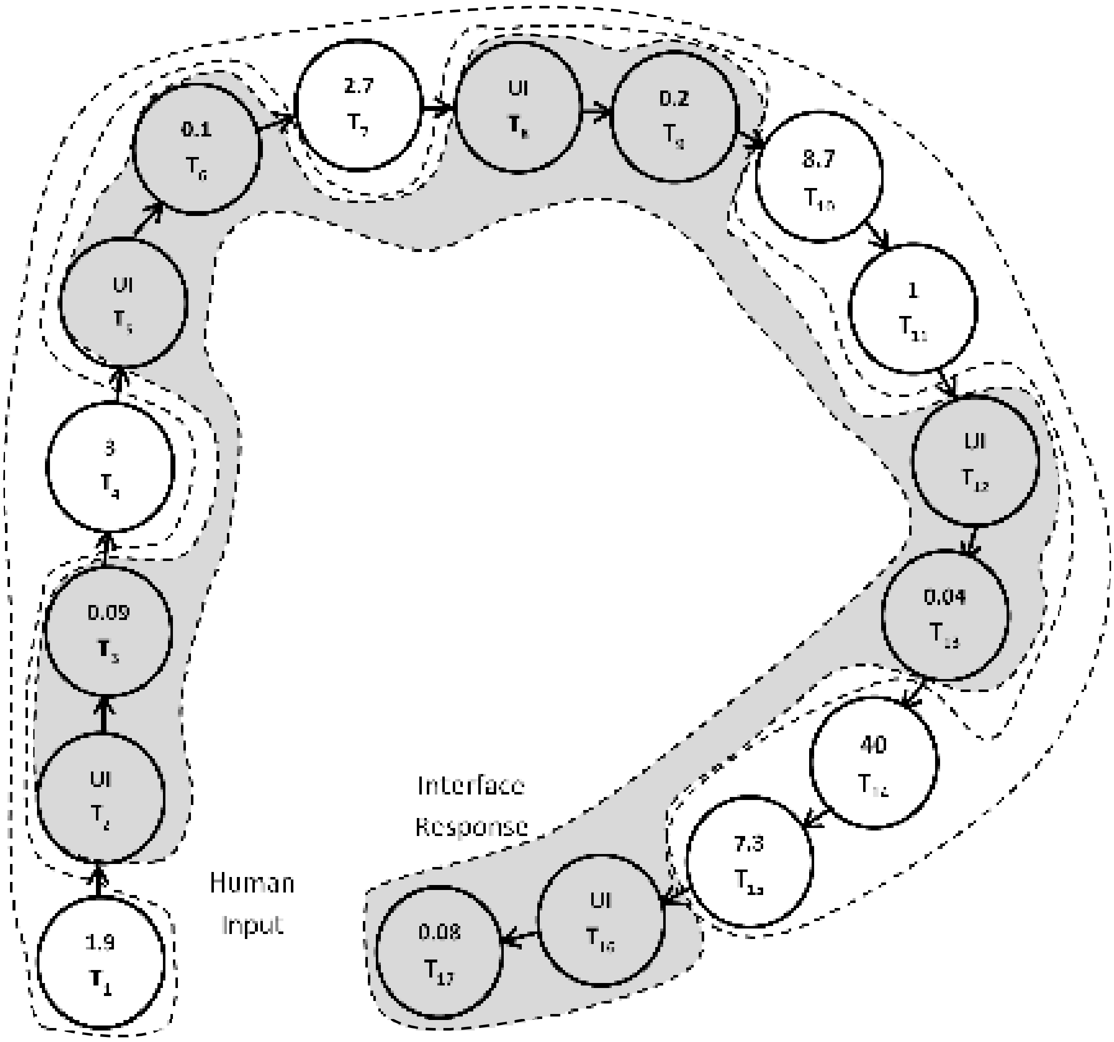

Figure 55. Task Graph for Send SMS function on OS5.

Set Appointment Task Graphs

This section includes the task graphs for the “set appointment” function for all the smartphone operating systems. The task number in the task graph is shown by a circle that contains Ti where i is the number of the task in the function and a number which shows the complexity of the task. If the task is performed by the internal part of the user interface and the complexity is unknown, the complexity will be displayed as UI.

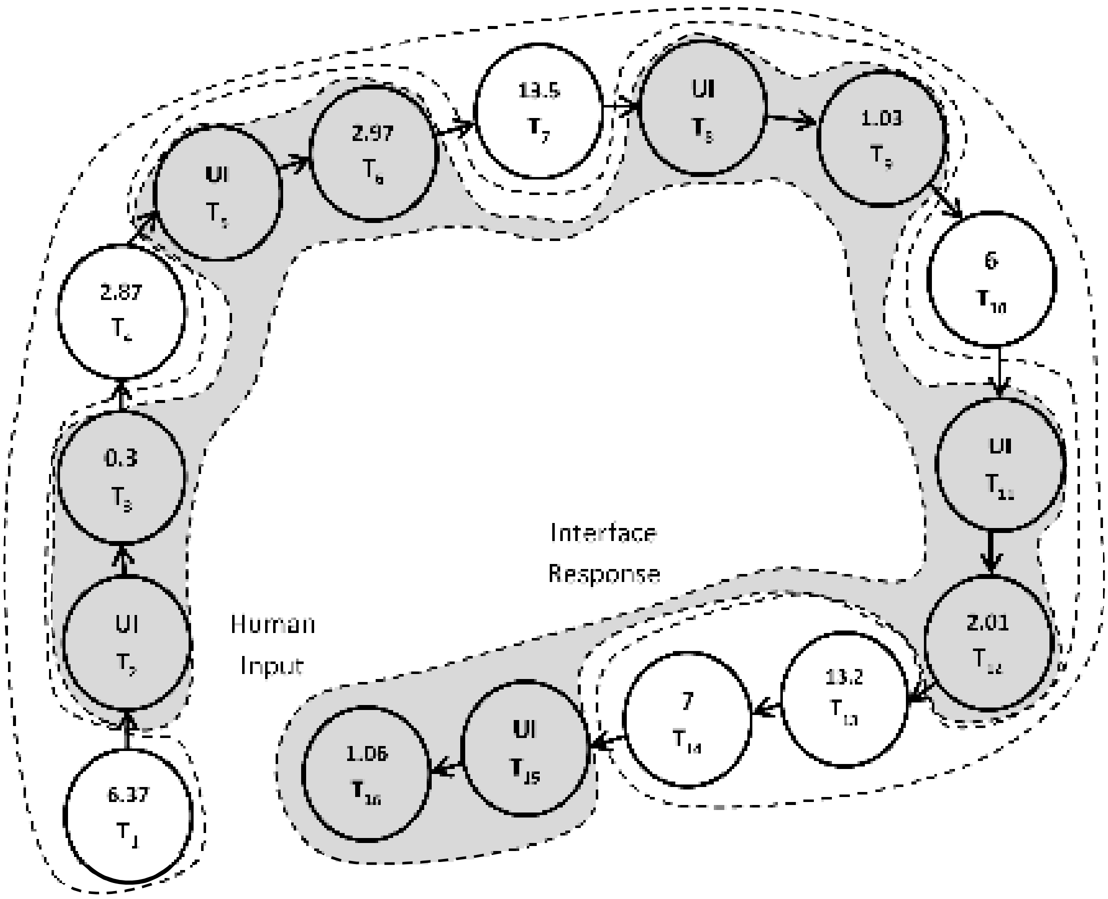

Figure 56. Task Graph for Set Appointment function on OS1.

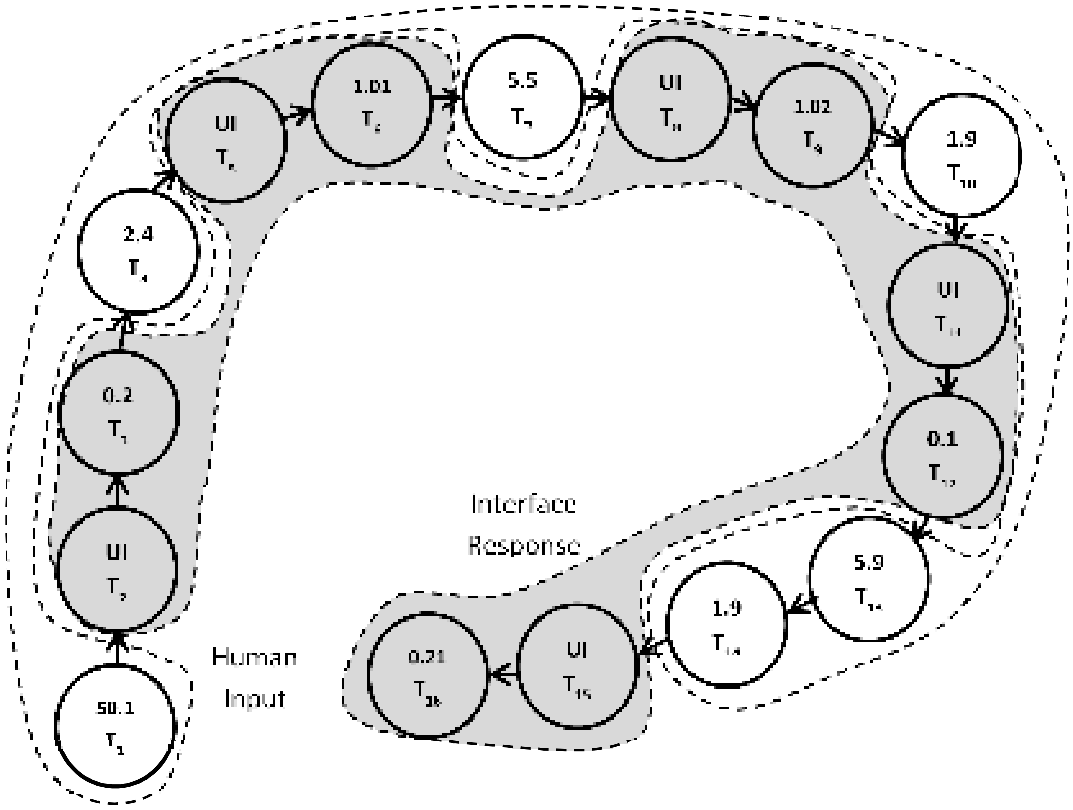

Figure 57. Task Graph for Set Appointment function on OS2.

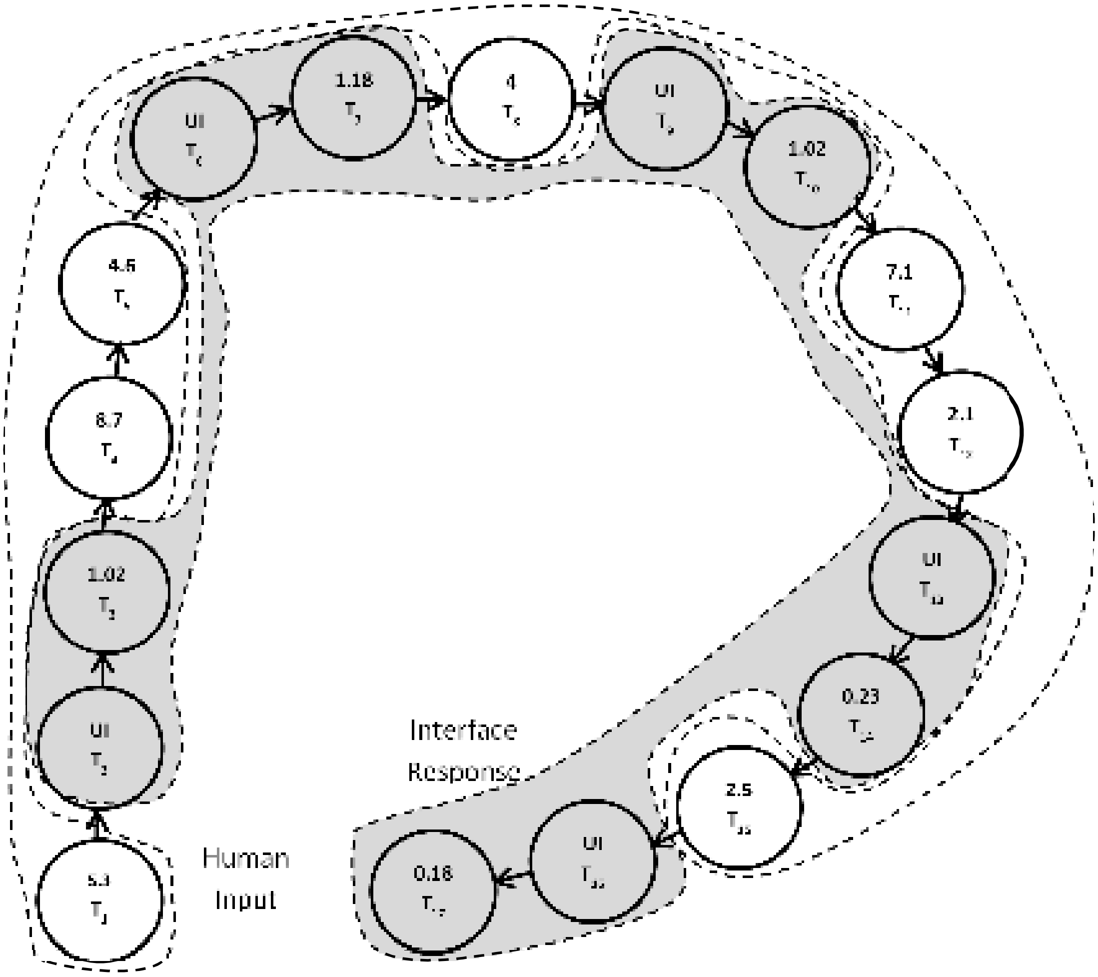

Figure 58. Task Graph for Set Appointment function on OS3.

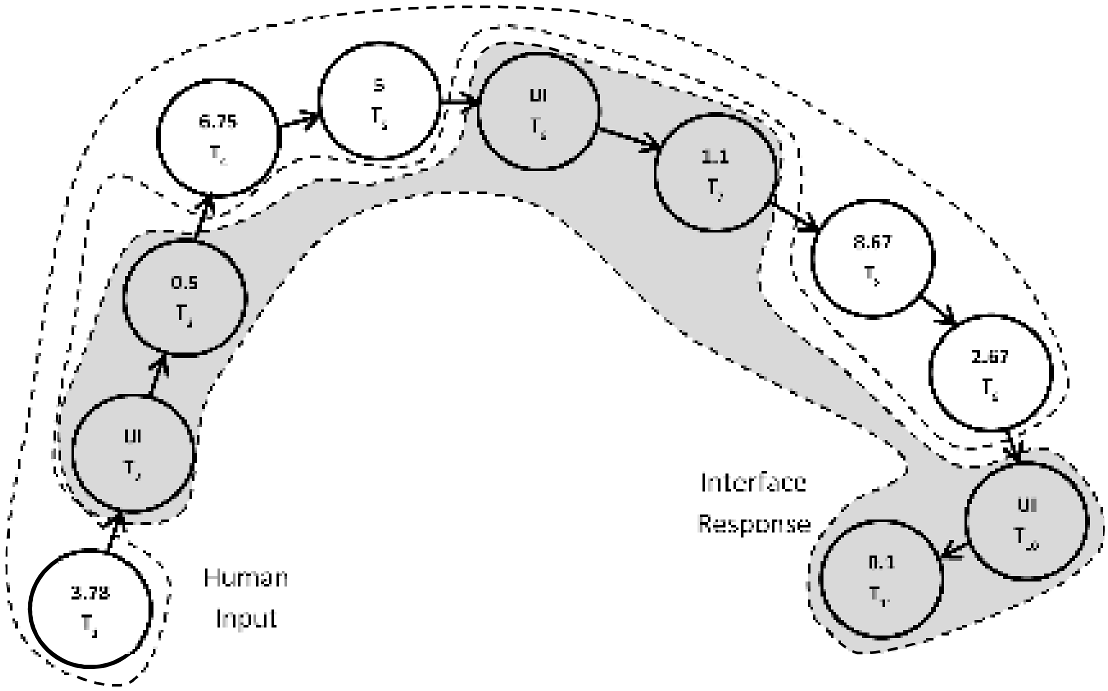

Figure 59. Task Graph for Set Appointment function on OS4.

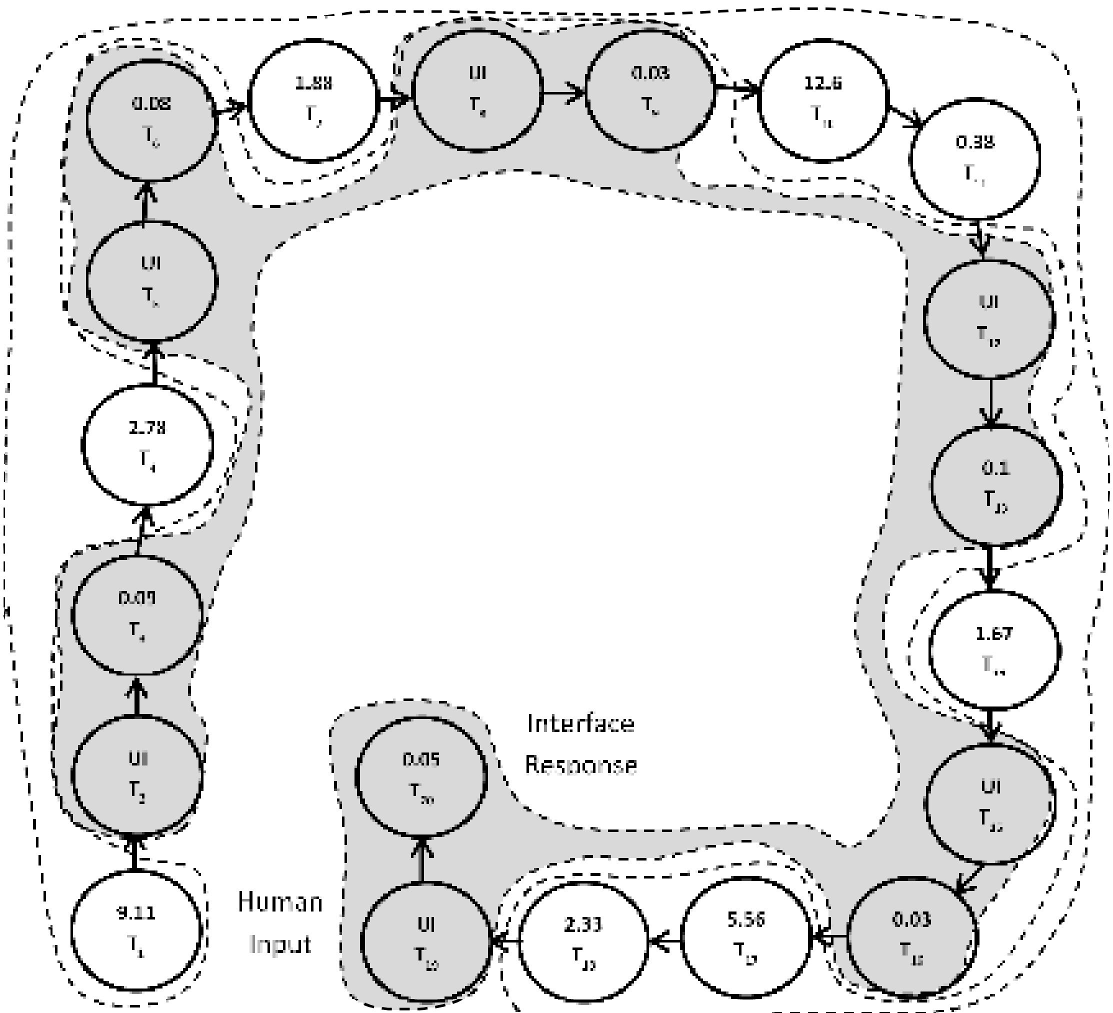

Figure 60. Task Graph for Set appointment function on OS5.

Go to Webpage Task Graphs

This section includes the task graphs for the "go to webpage" function for all the smartphone operating systems. The task number in the task graph is shown by a circle that contains **T_i** where **i** is the number of the task in the function and a number which shows the complexity of the task. If the task is performed by the internal part of the user interface and the complexity is unknown, the complexity will be displayed as UI.

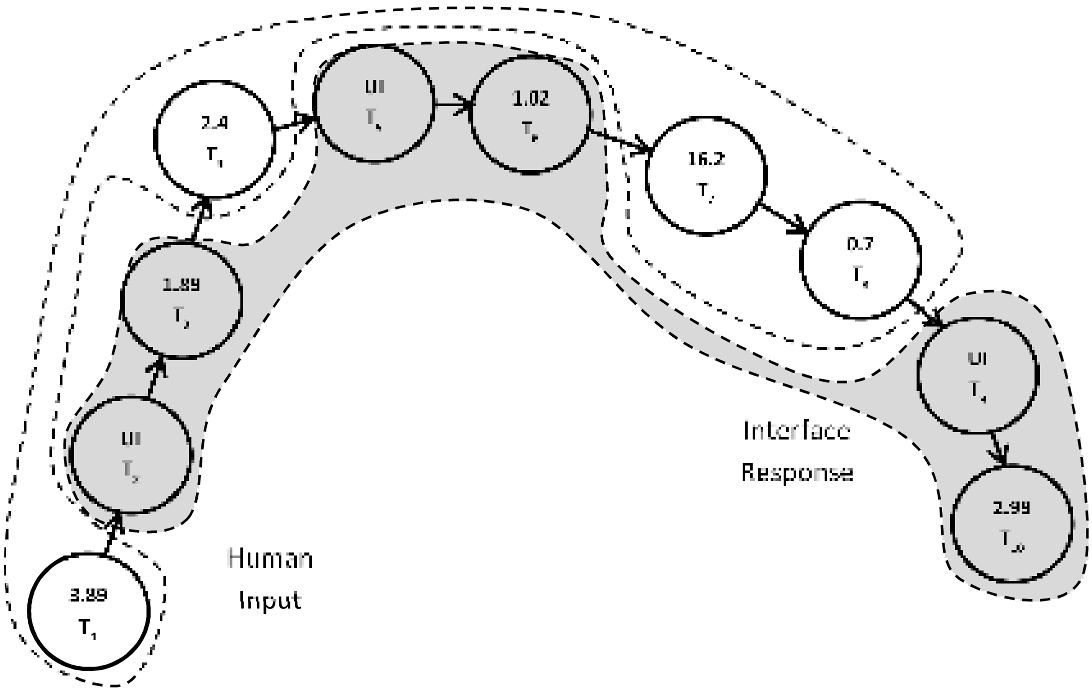

Figure 61. Task Graph for Go to Webpage function on OS1.

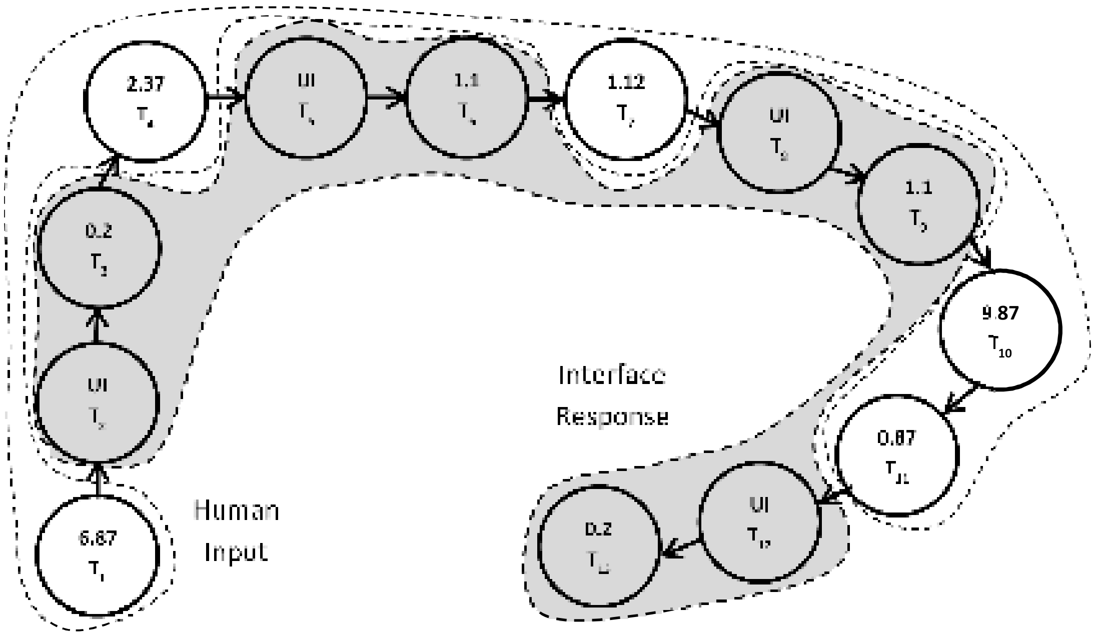

Figure 63. Task Graph for Go to Webpage function on OS2.

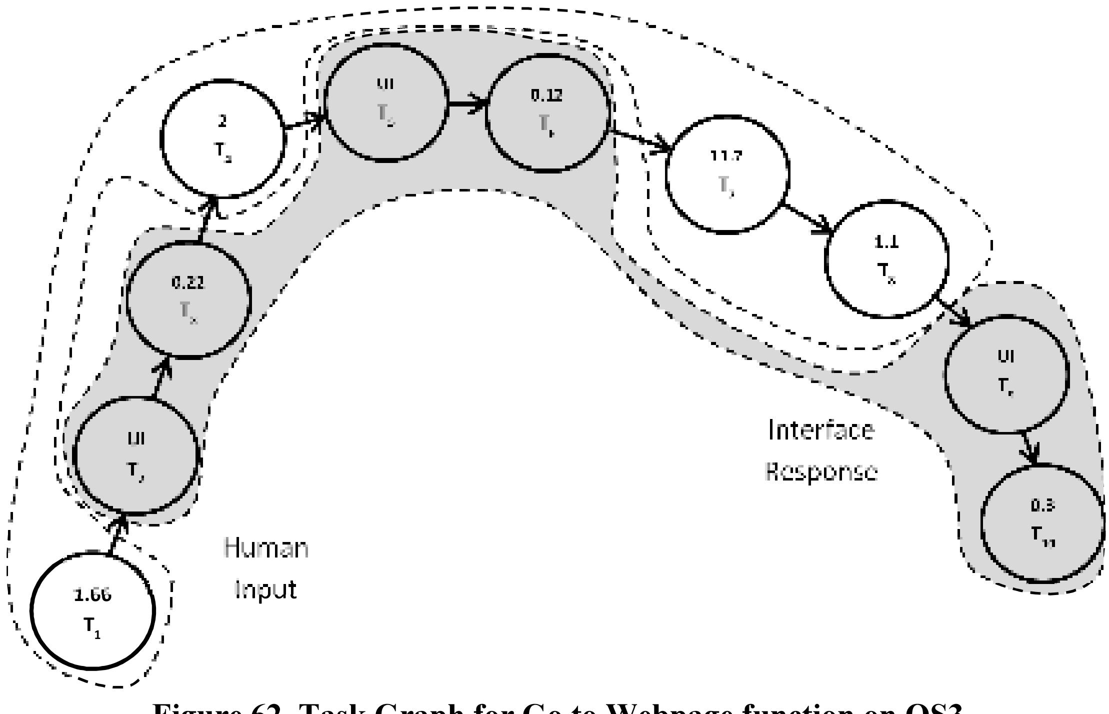

Figure 62. Task Graph for Go to Webpage function on OS3.

Appendix C

This is the CIQ function which has two parameters passed to it: A and t, where A is the data allocation matrix and t is the complexity matrix.

```
function x = CIQ (A, t)
NumOfTasks = length(A);
CIQ1 = 0;
CIQ2 = 0;

for i = 1 : NumOfTasks
    CIQ1 = CIQ1 + (A(i,1) * t(i));
end;
for j = 1 : NumOfTasks
    CIQ2 = CIQ2 + (A(j,2) * t(j));
end;
x = CIQ1 + CIQ2;
```

This is the HIQ function which has five parameters passed to it: A, t, F, Chm and Cmh, where A is the data allocation matrix, t is the complexity matrix and F is the data transfer matrix.

```
function ans = HIQ(A,t,F,Chm,Cmh)
NumOfTasks = length(A);
HIQ1 = 0;
HIQ2 = 0;
HIQ3 = 0;

for i = 1 : NumOfTasks
    HIQ1 = HIQ1 + (A(i,2) * t(i));
end;

for i = 1 : NumOfTasks
for j = 1 : NumOfTasks
        HIQ2 = HIQ2 + (A(i,1) * A(j,2) * F(i,j));
end;
end;

HIQ2 = HIQ2 * Cmh;

for i = 1 : NumOfTasks
for j = 1 : NumOfTasks
        HIQ3 = HIQ3 + (A(i,2) * A(j,1) * F(i,j));
end;
end;

HIQ3 = HIQ3 * Chm;

ans = HIQ1+HIQ2+HIQ3;
```

Appendix D

OS1 “Make a Call” Task

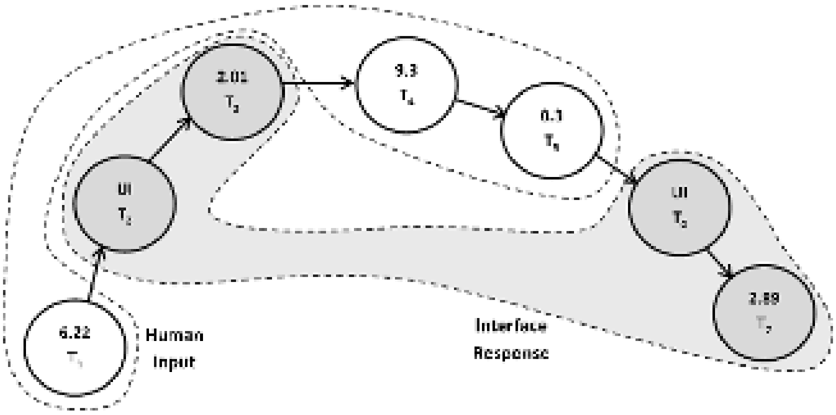

Figure 64. OS1 “make a call” task graph.

Table 24. OS1 “make a call” subtask complexities.

Task	Make a Call	Average
1	Locate Phone Application	6.222222
2	Response from Phone	UI
3	Response from Phone	2.01
4	Dial Numbers	9.3
5	Click Call	0.3
6	Response from Phone	UI
7	Response from Phone	2.89

Task Set:

$T = \{T_1, T_2, T_3, T_4, T_5, T_6, T_7\}$

Complexity Set:

$\tau = \{\tau_1, \tau_2, \tau_3, \tau_4, \tau_5, \tau_6, \tau_7\}$

$\tau = \{6.22, \tau_2, 2.01, 9.3, 0.3, \tau_6, 2.89\}$

Data Transfer Matrix:

$$F = \begin{bmatrix} 0 & f_{12} & f_{13} & f_{14} & f_{15} & f_{16} & f_{17} \\ f_{21} & 0 & f_{23} & f_{24} & f_{25} & f_{26} & f_{27} \\ f_{31} & f_{32} & 0 & f_{34} & f_{35} & f_{36} & f_{37} \\ f_{41} & f_{42} & f_{43} & 0 & f_{45} & f_{46} & f_{47} \\ f_{51} & f_{52} & f_{53} & f_{54} & 0 & f_{56} & f_{57} \\ f_{61} & f_{62} & f_{63} & f_{64} & f_{65} & 0 & f_{67} \\ f_{71} & f_{72} & f_{73} & f_{74} & f_{75} & f_{76} & 0 \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 11 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

Task Allocation Matrix:

$$A = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \\ a_{31} & a_{32} \\ a_{41} & a_{42} \\ a_{51} & a_{52} \\ a_{61} & a_{62} \\ a_{71} & a_{72} \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ 1 & 0 \\ 1 & 1 \\ 0 & 1 \\ 0 & 1 \\ 1 & 0 \\ 1 & 0 \end{bmatrix}$$

Using the Matlab HIQ function with the above data we get: **HIQ = 21;** hence **UIQ = 50 – 21 = 29**

OS1 “Send a Message” Task

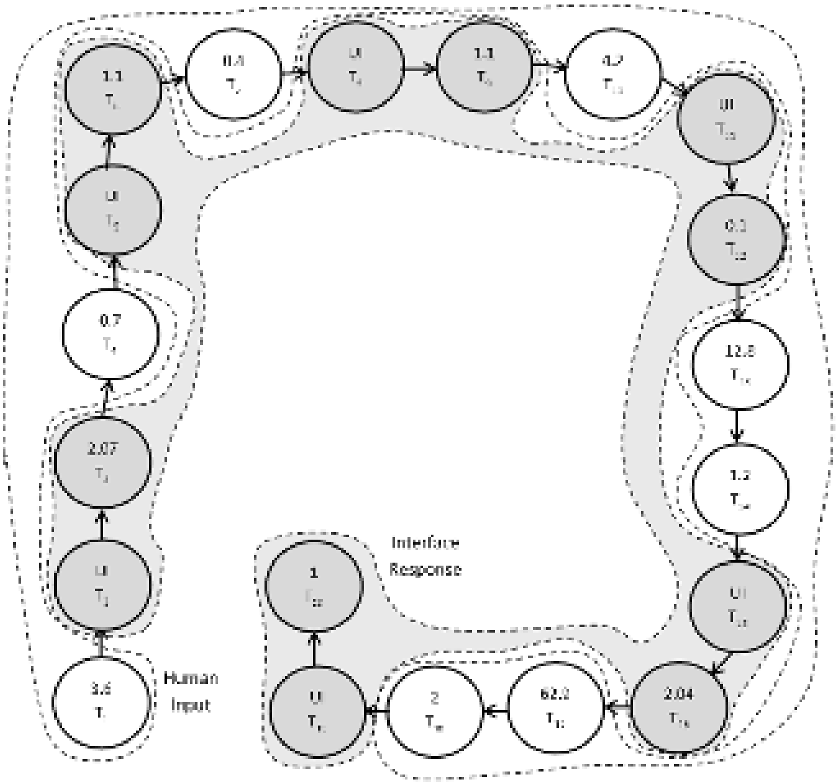

Figure 65. OS1 “send a message” task graph.

Table 25. OS1 send a message subtasks complexities.

Task	Send SMS	Average
1	Locate Messaging Application	3.6
2	Response from Phone	UI
3	Response from Phone	2.07
4	Select new message	0.7
5	Response from Phone	UI
6	Response from Phone	1.1
7	Select "to" box	0.4
8	Response from Phone	UI
9	Response from Phone	1.1
10	Select Digit view	4.2
11	Response from Phone	UI
12	Response from Phone	0.1
13	Enter numbers	12.8
14	Click next	1.2
15	Response from Phone	UI
16	Response from Phone	2.04
17	Enter Text Message	62.9
18	Click Send	2
19	Response from Phone	UI
20	Response from Phone	1

Task Set:

$T = \{T_1, T_2, T_3, T_4, T_5, T_6, T_7, T_8, T_9, T_{10}, T_{11}, T_{12}, T_{13}, T_{14}, T_{15}, T_{16}, T_{17}, T_{18}, T_{19}, T_{20}\}$

Difficulty Set:

$\tau = \{\tau_1, \tau_2, \tau_3, \tau_4, \tau_5, \tau_6, \tau_7, \tau_8, \tau_9, \tau_{10}, \tau_{11}, \tau_{12}, \tau_{13}, \tau_{14}, \tau_{15}, \tau_{16}, \tau_{17}, \tau_{18}, \tau_{19}, \tau_{20}\}$

$\tau = \{3.6, \tau_2, 2.07, 0.7, \tau_5, 1.1, 0.4, \tau_8, 1.1, 4.2, \tau_{11}, 0.1, 12.8, 1.2, \tau_{15}, 2.04, 62.9, 2, \tau_{19}, 1\}$

Data Transfer Matrix:

$$F = \begin{bmatrix}
0 & f_{12} & f_{13} & f_{14} & f_{15} & f_{16} & f_{17} & f_{18} & f_{19} & f_{110} & f_{111} & f_{112} & f_{113} & f_{114} & f_{115} & f_{116} & f_{117} & f_{118} & f_{119} & f_{120} \\
f_{21} & 0 & f_{23} & f_{24} & f_{25} & f_{26} & f_{27} & f_{28} & f_{29} & f_{210} & f_{211} & f_{212} & f_{213} & f_{214} & f_{215} & f_{216} & f_{217} & f_{218} & f_{219} & f_{220} \\
f_{31} & f_{32} & 0 & f_{34} & f_{35} & f_{36} & f_{37} & f_{38} & f_{39} & f_{310} & f_{311} & f_{312} & f_{313} & f_{314} & f_{315} & f_{316} & f_{317} & f_{318} & f_{319} & f_{320} \\
f_{41} & f_{42} & f_{43} & 0 & f_{45} & f_{46} & f_{47} & f_{48} & f_{49} & f_{410} & f_{411} & f_{412} & f_{413} & f_{414} & f_{415} & f_{416} & f_{417} & f_{418} & f_{419} & f_{420} \\
f_{51} & f_{52} & f_{53} & f_{54} & 0 & f_{56} & f_{57} & f_{58} & f_{59} & f_{510} & f_{511} & f_{512} & f_{513} & f_{514} & f_{515} & f_{516} & f_{517} & f_{518} & f_{519} & f_{520} \\
f_{61} & f_{62} & f_{63} & f_{64} & f_{65} & 0 & f_{67} & f_{68} & f_{69} & f_{610} & f_{611} & f_{612} & f_{613} & f_{614} & f_{615} & f_{616} & f_{617} & f_{618} & f_{619} & f_{620} \\
f_{71} & f_{72} & f_{73} & f_{74} & f_{75} & f_{76} & 0 & f_{78} & f_{79} & f_{710} & f_{711} & f_{712} & f_{713} & f_{714} & f_{715} & f_{716} & f_{717} & f_{718} & f_{719} & f_{720} \\
f_{81} & f_{82} & f_{83} & f_{84} & f_{85} & f_{86} & f_{87} & 0 & f_{89} & f_{810} & f_{811} & f_{812} & f_{813} & f_{814} & f_{815} & f_{816} & f_{817} & f_{818} & f_{819} & f_{820} \\
f_{91} & f_{92} & f_{93} & f_{94} & f_{95} & f_{96} & f_{97} & f_{98} & 0 & f_{910} & f_{911} & f_{912} & f_{913} & f_{914} & f_{915} & f_{916} & f_{917} & f_{918} & f_{919} & f_{920} \\
f_{101} & f_{102} & f_{103} & f_{104} & f_{105} & f_{106} & f_{107} & f_{108} & f_{109} & 0 & f_{1010} & f_{1011} & f_{1013} & f_{1014} & f_{1015} & f_{1016} & f_{1017} & f_{1018} & f_{1019} & f_{1020} \\
f_{111} & f_{112} & f_{113} & f_{114} & f_{115} & f_{116} & f_{117} & f_{118} & f_{119} & f_{1110} & 0 & f_{1112} & f_{1113} & f_{1114} & f_{1115} & f_{1116} & f_{1117} & f_{1118} & f_{1119} & f_{1120} \\
f_{121} & f_{122} & f_{123} & f_{124} & f_{125} & f_{126} & f_{127} & f_{128} & f_{129} & f_{1210} & f_{1211} & 0 & f_{1213} & f_{1214} & f_{1215} & f_{1216} & f_{1217} & f_{1218} & f_{1219} & f_{1220} \\
f_{131} & f_{132} & f_{133} & f_{134} & f_{135} & f_{136} & f_{137} & f_{138} & f_{139} & f_{1310} & f_{1311} & f_{1312} & 0 & f_{1314} & f_{1315} & f_{1316} & f_{1317} & f_{1318} & f_{1319} & f_{1320} \\
f_{141} & f_{142} & f_{143} & f_{144} & f_{145} & f_{146} & f_{147} & f_{148} & f_{149} & f_{1410} & f_{1411} & f_{1412} & f_{1413} & 0 & f_{1415} & f_{1416} & f_{1417} & f_{1418} & f_{1419} & f_{1420} \\
f_{151} & f_{152} & f_{153} & f_{154} & f_{155} & f_{156} & f_{157} & f_{158} & f_{159} & f_{1510} & f_{1511} & f_{1512} & f_{1513} & f_{1514} & 0 & f_{1516} & f_{1517} & f_{1518} & f_{1519} & f_{1520} \\
f_{161} & f_{162} & f_{163} & f_{164} & f_{165} & f_{166} & f_{167} & f_{168} & f_{169} & f_{1610} & f_{1611} & f_{1612} & f_{1613} & f_{1614} & f_{1615} & 0 & f_{1617} & f_{1618} & f_{1619} & f_{1620} \\
f_{171} & f_{172} & f_{173} & f_{174} & f_{175} & f_{176} & f_{177} & f_{178} & f_{179} & f_{1710} & f_{1711} & f_{1712} & f_{1713} & f_{1714} & f_{1715} & f_{1716} & 0 & f_{1718} & f_{1719} & f_{1720} \\
f_{181} & f_{182} & f_{183} & f_{184} & f_{185} & f_{186} & f_{187} & f_{188} & f_{189} & f_{1810} & f_{1811} & f_{1812} & f_{1813} & f_{1814} & f_{1815} & f_{1816} & f_{1817} & 0 & f_{1819} & f_{1820} \\
f_{191} & f_{192} & f_{193} & f_{194} & f_{195} & f_{196} & f_{197} & f_{198} & f_{199} & f_{1910} & f_{1911} & f_{1912} & f_{1913} & f_{1914} & f_{1915} & f_{1916} & f_{1917} & f_{1918} & 0 & f_{1920} \\
f_{201} & f_{202} & f_{203} & f_{204} & f_{205} & f_{206} & f_{207} & f_{208} & f_{209} & f_{2010} & f_{2011} & f_{2012} & f_{2013} & f_{2014} & f_{2015} & f_{2016} & f_{2017} & f_{2018} & f_{2019} & 0
\end{bmatrix}$$

$$= \begin{bmatrix}
0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 10 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 37 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0
\end{bmatrix}$$

Task Allocation Matrix:

$$
A = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \\ a_{31} & a_{32} \\ a_{41} & a_{42} \\ a_{51} & a_{52} \\ a_{61} & a_{62} \\ a_{71} & a_{72} \\ a_{81} & a_{82} \\ a_{91} & a_{92} \\ a_{101} & a_{102} \\ a_{111} & a_{112} \\ a_{121} & a_{122} \\ a_{131} & a_{132} \\ a_{141} & a_{142} \\ a_{151} & a_{152} \\ a_{161} & a_{162} \\ a_{171} & a_{172} \\ a_{181} & a_{182} \\ a_{191} & a_{192} \\ a_{201} & a_{202} \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ 1 & 0 \\ 1 & 0 \\ 0 & 1 \\ 1 & 0 \\ 1 & 0 \\ 0 & 1 \\ 1 & 0 \\ 1 & 0 \\ 0 & 1 \\ 1 & 0 \\ 1 & 0 \\ 0 & 1 \\ 0 & 1 \\ 1 & 0 \\ 1 & 0 \\ 0 & 1 \\ 0 & 1 \\ 1 & 0 \\ 1 & 0 \end{bmatrix}
$$

Using the Matlab HIQ function with the above data we get: **HIQ = 110.917;** hence **UIQ = 200 – 110.917 = 89.083**

OS1 Set Appointment Task

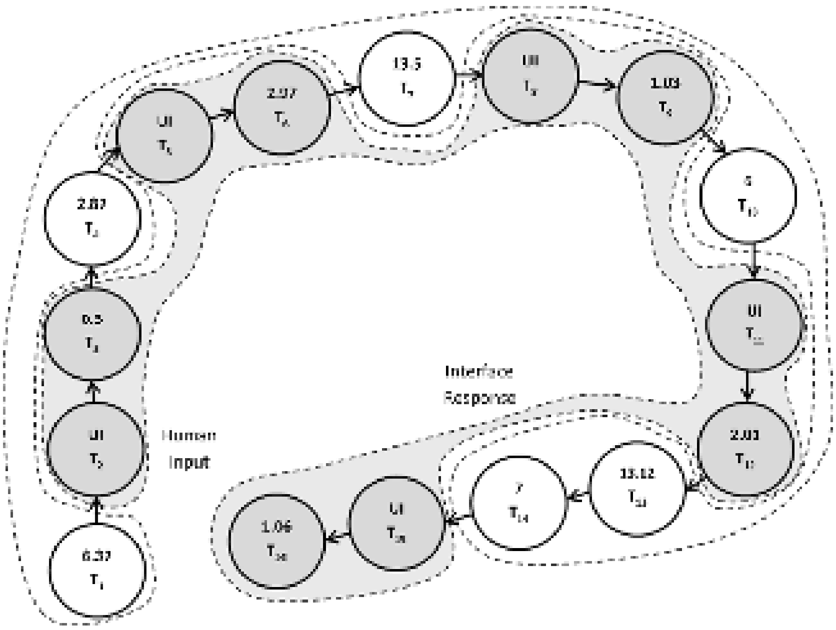

Figure 66. OS1 set appointment task graph.

Table 26. OS1 "set appointment" subtask complexities.

Task	Set Appointment	Average
1	Click on Applications	6.375
2	Response from Phone	UI
3	Response from Phone	0.3
4	Locate Calendar Application	2.875
5	Response from Phone	UI
6	Response from Phone	2.97
7	Locate Date	13.5
8	Response from Phone	UI
9	Response from Phone	1.03
10	Click Add	6
11	Response from Phone	UI
12	Response from Phone	2.01
13	Type Name of Appointment	13.125
14	Click Done	7
15	Response from Phone	UI
16	Response from Phone	1.06

Task Set:

$T = \{T_1, T_2, T_3, T_4, T_5, T_6, T_7, T_8, T_9, T_{10}, T_{11}, T_{12}, T_{13}, T_{14}, T_{15}, T_{16}\}$

Difficulty Set:

$\tau = \{\tau_1, \tau_2, \tau_3, \tau_4, \tau_5, \tau_6, \tau_7, \tau_8, \tau_9, \tau_{10}, \tau_{11}, \tau_{12}, \tau_{13}, \tau_{14}, \tau_{15}, \tau_{16}\}$

$\tau = \{6.375, \tau_2, 0.3, 2.875, \tau_5, 2.97, 13.5, \tau_8, 1.03, 6, \tau_{11}, 2.01, 13.125, 7, \tau_{15}, 1.06\}$

Data Transfer Matrix:

$$F = \begin{bmatrix}
0 & f_{12} & f_{13} & f_{14} & f_{15} & f_{16} & f_{17} & f_{18} & f_{19} & f_{110} & f_{111} & f_{112} & f_{113} & f_{114} & f_{115} & f_{116} \\
f_{21} & 0 & f_{23} & f_{24} & f_{25} & f_{26} & f_{27} & f_{28} & f_{29} & f_{210} & f_{211} & f_{212} & f_{213} & f_{214} & f_{215} & f_{216} \\
f_{31} & f_{32} & 0 & f_{34} & f_{35} & f_{36} & f_{37} & f_{38} & f_{39} & f_{310} & f_{311} & f_{312} & f_{313} & f_{314} & f_{315} & f_{316} \\
f_{41} & f_{42} & f_{43} & 0 & f_{45} & f_{46} & f_{47} & f_{48} & f_{49} & f_{410} & f_{411} & f_{412} & f_{413} & f_{414} & f_{415} & f_{416} \\
f_{51} & f_{52} & f_{53} & f_{54} & 0 & f_{56} & f_{57} & f_{58} & f_{59} & f_{510} & f_{511} & f_{512} & f_{513} & f_{514} & f_{515} & f_{516} \\
f_{61} & f_{62} & f_{63} & f_{64} & f_{65} & 0 & f_{67} & f_{68} & f_{69} & f_{610} & f_{611} & f_{612} & f_{613} & f_{614} & f_{615} & f_{616} \\
f_{71} & f_{72} & f_{73} & f_{74} & f_{75} & f_{76} & 0 & f_{78} & f_{79} & f_{710} & f_{711} & f_{712} & f_{713} & f_{714} & f_{715} & f_{716} \\
f_{81} & f_{82} & f_{83} & f_{84} & f_{85} & f_{86} & f_{87} & 0 & f_{89} & f_{810} & f_{811} & f_{812} & f_{813} & f_{814} & f_{815} & f_{816} \\
f_{91} & f_{92} & f_{93} & f_{94} & f_{95} & f_{96} & f_{97} & f_{98} & 0 & f_{910} & f_{911} & f_{912} & f_{913} & f_{914} & f_{915} & f_{916} \\
f_{101} & f_{102} & f_{103} & f_{104} & f_{105} & f_{106} & f_{107} & f_{108} & f_{109} & 0 & f_{1010} & f_{1011} & f_{1013} & f_{1014} & f_{1015} & f_{1016} \\
f_{111} & f_{112} & f_{113} & f_{114} & f_{115} & f_{116} & f_{117} & f_{118} & f_{119} & f_{1110} & 0 & f_{1112} & f_{1113} & f_{1114} & f_{1115} & f_{1116} \\
f_{121} & f_{122} & f_{123} & f_{124} & f_{125} & f_{126} & f_{127} & f_{128} & f_{129} & f_{1210} & f_{1211} & 0 & f_{1213} & f_{1214} & f_{1215} & f_{1216} \\
f_{131} & f_{132} & f_{133} & f_{134} & f_{135} & f_{136} & f_{137} & f_{138} & f_{139} & f_{1310} & f_{1311} & f_{1312} & 0 & f_{1314} & f_{1315} & f_{1316} \\
f_{141} & f_{142} & f_{143} & f_{144} & f_{145} & f_{146} & f_{147} & f_{148} & f_{149} & f_{1410} & f_{1411} & f_{1412} & f_{1413} & 0 & f_{1415} & f_{1416} \\
f_{151} & f_{152} & f_{153} & f_{154} & f_{155} & f_{156} & f_{157} & f_{158} & f_{159} & f_{1510} & f_{1511} & f_{1512} & f_{1513} & f_{1514} & 0 & f_{1516} \\
f_{161} & f_{162} & f_{163} & f_{164} & f_{165} & f_{166} & f_{167} & f_{168} & f_{169} & f_{1610} & f_{1611} & f_{1612} & f_{1613} & f_{1614} & f_{1615} & 0
\end{bmatrix}$$

$$= \begin{bmatrix}
0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 10 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 8 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0
\end{bmatrix}$$

Task Allocation Matrix:

$$A = \begin{bmatrix}
a_{11} & a_{12} \\
a_{21} & a_{22} \\
a_{31} & a_{32} \\
a_{41} & a_{42} \\
a_{51} & a_{52} \\
a_{61} & a_{62} \\
a_{71} & a_{72} \\
a_{81} & a_{82} \\
a_{91} & a_{92} \\
a_{101} & a_{102} \\
a_{111} & a_{112} \\
a_{121} & a_{122} \\
a_{131} & a_{132} \\
a_{141} & a_{142} \\
a_{151} & a_{152} \\
a_{161} & a_{162}
\end{bmatrix} = \begin{bmatrix}
0 & 1 \\
1 & 0 \\
1 & 0 \\
0 & 1 \\
1 & 0 \\
1 & 0 \\
0 & 1 \\
1 & 0 \\
1 & 0 \\
0 & 1 \\
1 & 0 \\
1 & 0 \\
0 & 1 \\
0 & 1 \\
1 & 0 \\
1 & 0
\end{bmatrix}$$

Using the Matlab HIQ function with the above data we get: **HIQ = 59.433** hence **UIQ = 100 – 59.433 = 40.567**

OS1 Go to Webpage Task

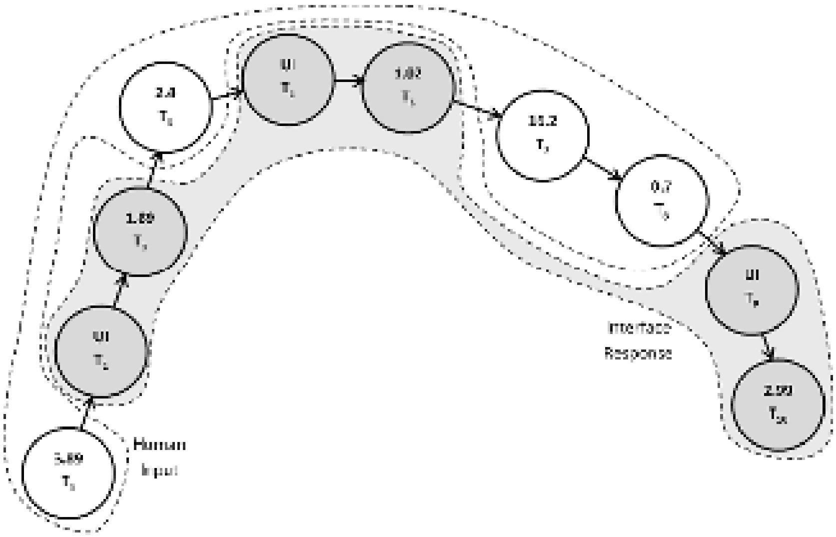

Figure 67. OS1 "go to webpage" task graph.

Table 27. OS1 "go to webpage" subtask complexities.

Task	Go To Webpage	Average
1	Locate Browser	3.888889
2	Response from Phone	UI
3	Response from Phone	1.89
4	Locate Address Area	2.4
5	Response from Phone	UI
6	Response from Phone	1.02
7	Enter Address	16.2
8	Click on Go	0.7
9	Response from Phone	UI
10	Response from Phone	2.99

Task Set:

$T = \{T_1, T_2, T_3, T_4, T_5, T_6, T_7, T_8, T_9, T_{10}\}$

Difficulty Set:

$\tau = \{\tau_1, \tau_2, \tau_3, \tau_4, \tau_5, \tau_6, \tau_7, \tau_8, \tau_9, \tau_{10}\}$

$\tau = \{3.89, \tau_2, 1.89, 2.4, \tau_5, 1.02, 16.2, 0.7, \tau_9, 2.99\}$

Data Transfer Matrix:

$$F = \begin{bmatrix} 0 & f_{12} & f_{13} & f_{14} & f_{15} & f_{16} & f_{17} & f_{18} & f_{19} & f_{110} \\ f_{21} & 0 & f_{23} & f_{24} & f_{25} & f_{26} & f_{27} & f_{28} & f_{29} & f_{210} \\ f_{31} & f_{32} & 0 & f_{34} & f_{35} & f_{36} & f_{37} & f_{38} & f_{39} & f_{310} \\ f_{41} & f_{42} & f_{43} & 0 & f_{45} & f_{46} & f_{47} & f_{48} & f_{49} & f_{410} \\ f_{51} & f_{52} & f_{53} & f_{54} & 0 & f_{56} & f_{57} & f_{58} & f_{59} & f_{510} \\ f_{61} & f_{62} & f_{63} & f_{64} & f_{65} & 0 & f_{67} & f_{68} & f_{69} & f_{610} \\ f_{71} & f_{72} & f_{73} & f_{74} & f_{75} & f_{76} & 0 & f_{78} & f_{79} & f_{710} \\ f_{81} & f_{82} & f_{83} & f_{84} & f_{85} & f_{86} & f_{87} & 0 & f_{89} & f_{810} \\ f_{91} & f_{92} & f_{93} & f_{94} & f_{95} & f_{96} & f_{97} & f_{98} & 0 & f_{910} \\ f_{101} & f_{102} & f_{103} & f_{104} & f_{105} & f_{106} & f_{107} & f_{108} & f_{109} & 0 \end{bmatrix}$$

$$= \begin{bmatrix} 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 11 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

Task Allocation Matrix:

$$A = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \\ a_{31} & a_{32} \\ a_{41} & a_{42} \\ a_{51} & a_{52} \\ a_{61} & a_{62} \\ a_{71} & a_{72} \\ a_{81} & a_{82} \\ a_{91} & a_{92} \\ a_{101} & a_{102} \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ 1 & 0 \\ 1 & 0 \\ 0 & 1 \\ 1 & 0 \\ 1 & 0 \\ 0 & 1 \\ 0 & 1 \\ 1 & 0 \\ 1 & 0 \end{bmatrix}$$

Using the Matlab HIQ function with the above data we get: **HIQ = 29.644;** hence **UIQ = 50 – 29.644 = 20.356**

OS2 "Make a Call" Task

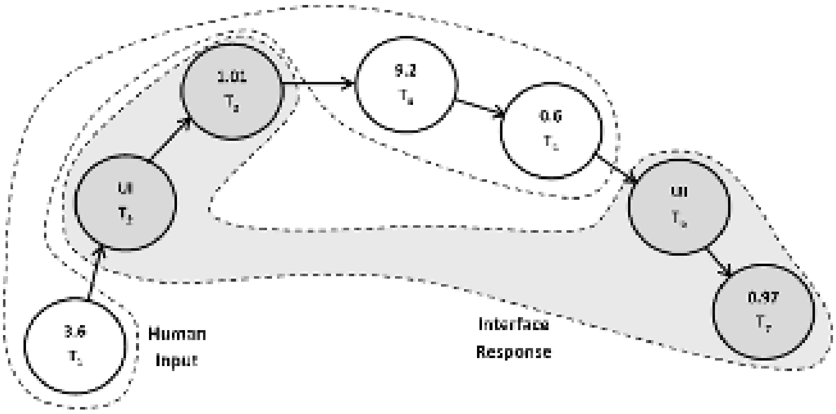

Figure 68. OS2 "make a call" task graph.

Table 28. OS2 "make a call" subtask complexities.

Task	Make a Call	Average
1	Locate Phone Application	3.6
2	Response from Phone	UI
3	Response from Phone	1.01
4	Dial Numbers	9.2
5	Click Call	0.6
6	Response from Phone	UI
7	Response from Phone	0.97

Task Set:

$T = \{T_1, T_2, T_3, T_4, T_5, T_6, T_7\}$

Difficulty Set:

$\tau = \{\tau_1, \tau_2, \tau_3, \tau_4, \tau_5, \tau_6, \tau_7\}$

$\tau = \{3.6, \tau_2, 1.01, 9.2, 0.6, \tau_6, 0.97\}$

Data Transfer Matrix:

$$F = \begin{bmatrix} 0 & f_{12} & f_{13} & f_{14} & f_{15} & f_{16} & f_{17} \\ f_{21} & 0 & f_{23} & f_{24} & f_{25} & f_{26} & f_{27} \\ f_{31} & f_{32} & 0 & f_{34} & f_{35} & f_{36} & f_{37} \\ f_{41} & f_{42} & f_{43} & 0 & f_{45} & f_{46} & f_{47} \\ f_{51} & f_{52} & f_{53} & f_{54} & 0 & f_{56} & f_{57} \\ f_{61} & f_{62} & f_{63} & f_{64} & f_{65} & 0 & f_{67} \\ f_{71} & f_{72} & f_{73} & f_{74} & f_{75} & f_{76} & 0 \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 11 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

Task Allocation Matrix:

$$A = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \\ a_{31} & a_{32} \\ a_{41} & a_{42} \\ a_{51} & a_{52} \\ a_{61} & a_{62} \\ a_{71} & a_{72} \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ 1 & 0 \\ 1 & 1 \\ 0 & 1 \\ 0 & 1 \\ 1 & 0 \\ 1 & 0 \end{bmatrix}$$

Using the Matlab HIQ function with the above data we get: **HIQ = 17.79;** hence **UIQ = 50 – 17.79 = 32.21**

OS2 “Send a Message” Task

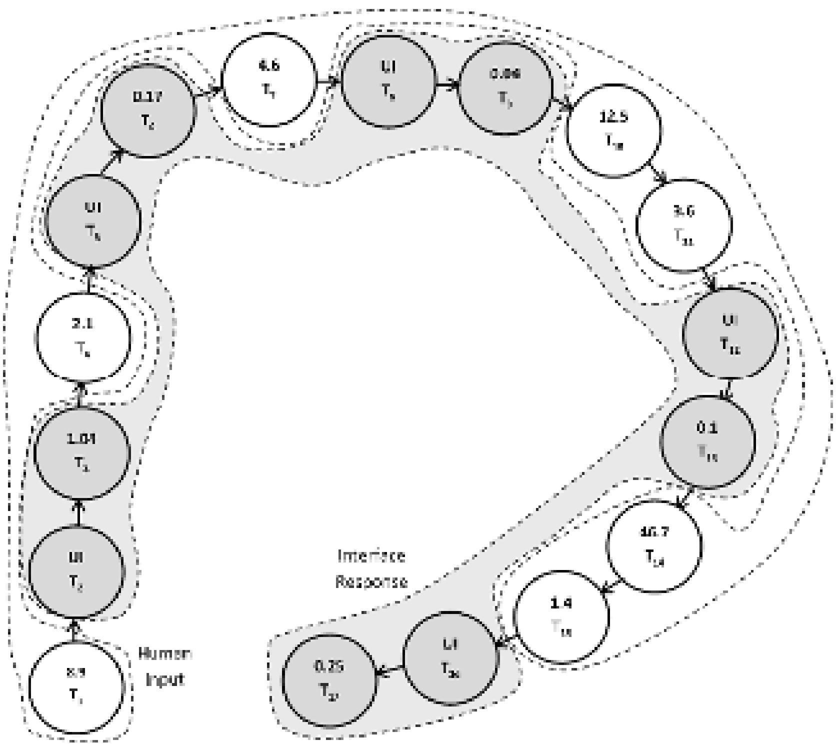

Figure 69. OS2 “send a message” task graph.

Table 29. OS2 "send a message" subtask complexities.

Task	Send SMS	Average
1	Locate Messaging Application	8.9
2	Response from Phone	UI
3	Response from Phone	1.04
4	Select new message	2.1
5	Response from Phone	UI
6	Response from Phone	0.17
7	Select Digit view	4.6
8	Response from Phone	UI
9	Response from Phone	0.04
10	Enter numbers	12.5
11	Select Text input area	3.6
12	Response from Phone	UI
13	Response from Phone	0.1
14	Enter Text Message	46.7
15	Click Send	1.4
16	Response from Phone	UI
17	Response from Phone	0.25

Task Set:

$T = \{T_1, T_2, T_3, T_4, T_5, T_6, T_7, T_8, T_9, T_{10}, T_{11}, T_{12}, T_{13}, T_{14}, T_{15}, T_{16}, T_{17}\}$

Difficulty Set:

$\tau = \{\tau_1, \tau_2, \tau_3, \tau_4, \tau_5, \tau_6, \tau_7, \tau_8, \tau_9, \tau_{10}, \tau_{11}, \tau_{12}, \tau_{13}, \tau_{14}, \tau_{15}, \tau_{16}, \tau_{17}\}$

$\tau = \{8.9, \tau_2, 1.04, 2.1, \tau_5, 0.17, 4.6, \tau_8, 0.04, 12.5, 3.6, \tau_{12}, 0.1, 46.7, 1.4, \tau_{16}, 0.25\}$

Data Transfer Matrix:

$$F = \begin{bmatrix}
0 & f_{12} & f_{13} & f_{14} & f_{15} & f_{16} & f_{17} & f_{18} & f_{19} & f_{110} & f_{111} & f_{112} & f_{113} & f_{114} & f_{115} & f_{116} & f_{117} \\
f_{21} & 0 & f_{23} & f_{24} & f_{25} & f_{26} & f_{27} & f_{28} & f_{29} & f_{210} & f_{211} & f_{212} & f_{213} & f_{214} & f_{215} & f_{216} & f_{217} \\
f_{31} & f_{32} & 0 & f_{34} & f_{35} & f_{36} & f_{37} & f_{38} & f_{39} & f_{310} & f_{311} & f_{312} & f_{313} & f_{314} & f_{315} & f_{316} & f_{317} \\
f_{41} & f_{42} & f_{43} & 0 & f_{45} & f_{46} & f_{47} & f_{48} & f_{49} & f_{410} & f_{411} & f_{412} & f_{413} & f_{414} & f_{415} & f_{416} & f_{417} \\
f_{51} & f_{52} & f_{53} & f_{54} & 0 & f_{56} & f_{57} & f_{58} & f_{59} & f_{510} & f_{511} & f_{512} & f_{513} & f_{514} & f_{515} & f_{516} & f_{517} \\
f_{61} & f_{62} & f_{63} & f_{64} & f_{65} & 0 & f_{67} & f_{68} & f_{69} & f_{610} & f_{611} & f_{612} & f_{613} & f_{614} & f_{615} & f_{616} & f_{617} \\
f_{71} & f_{72} & f_{73} & f_{74} & f_{75} & f_{76} & 0 & f_{78} & f_{79} & f_{710} & f_{711} & f_{712} & f_{713} & f_{714} & f_{715} & f_{716} & f_{717} \\
f_{81} & f_{82} & f_{83} & f_{84} & f_{85} & f_{86} & f_{87} & 0 & f_{89} & f_{810} & f_{811} & f_{812} & f_{813} & f_{814} & f_{815} & f_{816} & f_{817} \\
f_{91} & f_{92} & f_{93} & f_{94} & f_{95} & f_{96} & f_{97} & f_{98} & 0 & f_{910} & f_{911} & f_{912} & f_{913} & f_{914} & f_{915} & f_{916} & f_{917} \\
f_{101} & f_{102} & f_{103} & f_{104} & f_{105} & f_{106} & f_{107} & f_{108} & f_{109} & 0 & f_{1010} & f_{1011} & f_{1013} & f_{1014} & f_{1015} & f_{1016} & f_{1017} \\
f_{111} & f_{112} & f_{113} & f_{114} & f_{115} & f_{116} & f_{117} & f_{118} & f_{119} & f_{1110} & 0 & f_{1112} & f_{1113} & f_{1114} & f_{1115} & f_{1116} & f_{1117} \\
f_{121} & f_{122} & f_{123} & f_{124} & f_{125} & f_{126} & f_{127} & f_{128} & f_{129} & f_{1210} & f_{1211} & 0 & f_{1213} & f_{1214} & f_{1215} & f_{1216} & f_{1217} \\
f_{131} & f_{132} & f_{133} & f_{134} & f_{135} & f_{136} & f_{137} & f_{138} & f_{139} & f_{1310} & f_{1311} & f_{1312} & 0 & f_{1314} & f_{1315} & f_{1316} & f_{1317} \\
f_{141} & f_{142} & f_{143} & f_{144} & f_{145} & f_{146} & f_{147} & f_{148} & f_{149} & f_{1410} & f_{1411} & f_{1412} & f_{1413} & 0 & f_{1415} & f_{1416} & f_{1417} \\
f_{151} & f_{152} & f_{153} & f_{154} & f_{155} & f_{156} & f_{157} & f_{158} & f_{159} & f_{1510} & f_{1511} & f_{1512} & f_{1513} & f_{1514} & 0 & f_{1516} & f_{1517} \\
f_{161} & f_{162} & f_{163} & f_{164} & f_{165} & f_{166} & f_{167} & f_{168} & f_{169} & f_{1610} & f_{1611} & f_{1612} & f_{1613} & f_{1614} & f_{1615} & 0 & f_{1617} \\
f_{171} & f_{172} & f_{173} & f_{174} & f_{175} & f_{176} & f_{177} & f_{178} & f_{179} & f_{1710} & f_{1711} & f_{1712} & f_{1713} & f_{1714} & f_{1715} & f_{1716} & 0
\end{bmatrix}$$

$$= \begin{bmatrix}
0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 10 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 37 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0
\end{bmatrix}$$

Task Allocation Matrix:

$$A = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \\ a_{31} & a_{32} \\ a_{41} & a_{42} \\ a_{51} & a_{52} \\ a_{61} & a_{62} \\ a_{71} & a_{72} \\ a_{81} & a_{82} \\ a_{91} & a_{92} \\ a_{101} & a_{102} \\ a_{111} & a_{112} \\ a_{121} & a_{122} \\ a_{131} & a_{132} \\ a_{141} & a_{142} \\ a_{151} & a_{152} \\ a_{161} & a_{162} \\ a_{171} & a_{172} \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ 1 & 0 \\ 1 & 0 \\ 0 & 1 \\ 1 & 0 \\ 1 & 0 \\ 0 & 1 \\ 1 & 0 \\ 1 & 0 \\ 0 & 1 \\ 0 & 1 \\ 1 & 0 \\ 1 & 0 \\ 0 & 1 \\ 0 & 1 \\ 1 & 0 \\ 1 & 0 \end{bmatrix}$$

Using the Matlab HIQ function with the above data we get: **HIQ = 98.24;** hence **UIQ = 200 – 98.24 = 101.76**

OS2 "Set Appointment" Task

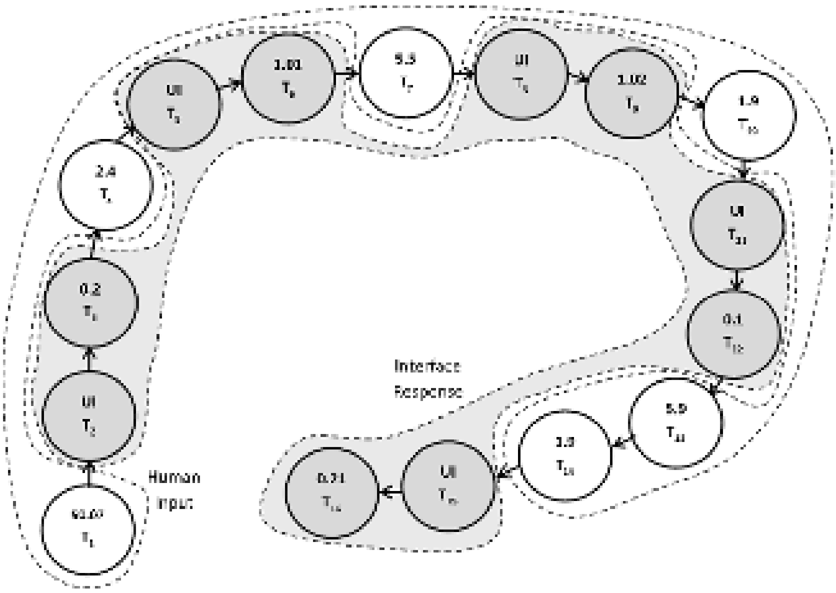

Figure 70. OS2 "set appointment" task graph.

Table 30. OS2 "set appointment" subtask complexities.

Task	Set Appointment	Average
1	Click on Applications	50.7
2	Response from Phone	UI
3	Response from Phone	0.2
4	Locate Calendar Application	2.4
5	Response from Phone	UI
6	Response from Phone	1.01
7	Locate Date	5.5
8	Response from Phone	UI
9	Response from Phone	1.02
10	Click Event Title	1.9
11	Response from Phone	UI
12	Response from Phone	0.1
13	Type Event Name	5.9
14	Click Save	1.9
15	Response from Phone	UI
16	Response from Phone	0.21

Task Set:

$T = \{T_1, T_2, T_3, T_4, T_5, T_6, T_7, T_8, T_9, T_{10}, T_{11}, T_{12}, T_{13}, T_{14}, T_{15}, T_{16}\}$

Difficulty Set:

$\tau = \{\tau_1, \tau_2, \tau_3, \tau_4, \tau_5, \tau_6, \tau_7, \tau_8, \tau_9, \tau_{10}, \tau_{11}, \tau_{12}, \tau_{13}, \tau_{14}, \tau_{15}, \tau_{16}\}$

$\tau = \{50.7, \tau_2, 0.2, 2.4, \tau_5, 1.01, 5.5, \tau_8, 1.02, 1.9, \tau_{11}, 0.1, 5.9, 1.9, \tau_{15}, 0.21\}$

Data Transfer Matrix:

$$F = \begin{bmatrix}
0 & f_{12} & f_{13} & f_{14} & f_{15} & f_{16} & f_{17} & f_{18} & f_{19} & f_{110} & f_{111} & f_{112} & f_{113} & f_{114} & f_{115} & f_{116} \\
f_{21} & 0 & f_{23} & f_{24} & f_{25} & f_{26} & f_{27} & f_{28} & f_{29} & f_{210} & f_{211} & f_{212} & f_{213} & f_{214} & f_{215} & f_{216} \\
f_{31} & f_{32} & 0 & f_{34} & f_{35} & f_{36} & f_{37} & f_{38} & f_{39} & f_{310} & f_{311} & f_{312} & f_{313} & f_{314} & f_{315} & f_{316} \\
f_{41} & f_{42} & f_{43} & 0 & f_{45} & f_{46} & f_{47} & f_{48} & f_{49} & f_{410} & f_{411} & f_{412} & f_{413} & f_{414} & f_{415} & f_{416} \\
f_{51} & f_{52} & f_{53} & f_{54} & 0 & f_{56} & f_{57} & f_{58} & f_{59} & f_{510} & f_{511} & f_{512} & f_{513} & f_{514} & f_{515} & f_{516} \\
f_{61} & f_{62} & f_{63} & f_{64} & f_{65} & 0 & f_{67} & f_{68} & f_{69} & f_{610} & f_{611} & f_{612} & f_{613} & f_{614} & f_{615} & f_{616} \\
f_{71} & f_{72} & f_{73} & f_{74} & f_{75} & f_{76} & 0 & f_{78} & f_{79} & f_{710} & f_{711} & f_{712} & f_{713} & f_{714} & f_{715} & f_{716} \\
f_{81} & f_{82} & f_{83} & f_{84} & f_{85} & f_{86} & f_{87} & 0 & f_{89} & f_{810} & f_{811} & f_{812} & f_{813} & f_{814} & f_{815} & f_{816} \\
f_{91} & f_{92} & f_{93} & f_{94} & f_{95} & f_{96} & f_{97} & f_{98} & 0 & f_{910} & f_{911} & f_{912} & f_{913} & f_{914} & f_{915} & f_{916} \\
f_{101} & f_{102} & f_{103} & f_{104} & f_{105} & f_{106} & f_{107} & f_{108} & f_{109} & 0 & f_{1010} & f_{1011} & f_{1013} & f_{1014} & f_{1015} & f_{1016} \\
f_{111} & f_{112} & f_{113} & f_{114} & f_{115} & f_{116} & f_{117} & f_{118} & f_{119} & f_{1110} & 0 & f_{1112} & f_{1113} & f_{1114} & f_{1115} & f_{1116} \\
f_{121} & f_{122} & f_{123} & f_{124} & f_{125} & f_{126} & f_{127} & f_{128} & f_{129} & f_{1210} & f_{1211} & 0 & f_{1213} & f_{1214} & f_{1215} & f_{1216} \\
f_{131} & f_{132} & f_{133} & f_{134} & f_{135} & f_{136} & f_{137} & f_{138} & f_{139} & f_{1310} & f_{1311} & f_{1312} & 0 & f_{1314} & f_{1315} & f_{1316} \\
f_{141} & f_{142} & f_{143} & f_{144} & f_{145} & f_{146} & f_{147} & f_{148} & f_{149} & f_{1410} & f_{1411} & f_{1412} & f_{1413} & 0 & f_{1415} & f_{1416} \\
f_{151} & f_{152} & f_{153} & f_{154} & f_{155} & f_{156} & f_{157} & f_{158} & f_{159} & f_{1510} & f_{1511} & f_{1512} & f_{1513} & f_{1514} & 0 & f_{1516} \\
f_{161} & f_{162} & f_{163} & f_{164} & f_{165} & f_{166} & f_{167} & f_{168} & f_{169} & f_{1610} & f_{1611} & f_{1612} & f_{1613} & f_{1614} & f_{1615} & 0
\end{bmatrix}$$

$$= \begin{bmatrix}
0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 10 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 8 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0
\end{bmatrix}$$

Task Allocation Matrix:

$$A = \begin{bmatrix}
a_{11} & a_{12} \\
a_{21} & a_{22} \\
a_{31} & a_{32} \\
a_{41} & a_{42} \\
a_{51} & a_{52} \\
a_{61} & a_{62} \\
a_{71} & a_{72} \\
a_{81} & a_{82} \\
a_{91} & a_{92} \\
a_{101} & a_{102} \\
a_{111} & a_{112} \\
a_{121} & a_{122} \\
a_{131} & a_{132} \\
a_{141} & a_{142} \\
a_{151} & a_{152} \\
a_{161} & a_{162}
\end{bmatrix} = \begin{bmatrix}
0 & 1 \\
1 & 0 \\
1 & 0 \\
0 & 1 \\
1 & 0 \\
1 & 0 \\
0 & 1 \\
1 & 0 \\
1 & 0 \\
0 & 1 \\
1 & 0 \\
1 & 0 \\
0 & 1 \\
0 & 1 \\
1 & 0 \\
1 & 0
\end{bmatrix}$$

Using the Matlab HIQ function with the above data we get: **HIQ = 80.24;** hence **UIQ = 100 – 80.24 = 19.76**

OS2 "Go to Webpage" Task

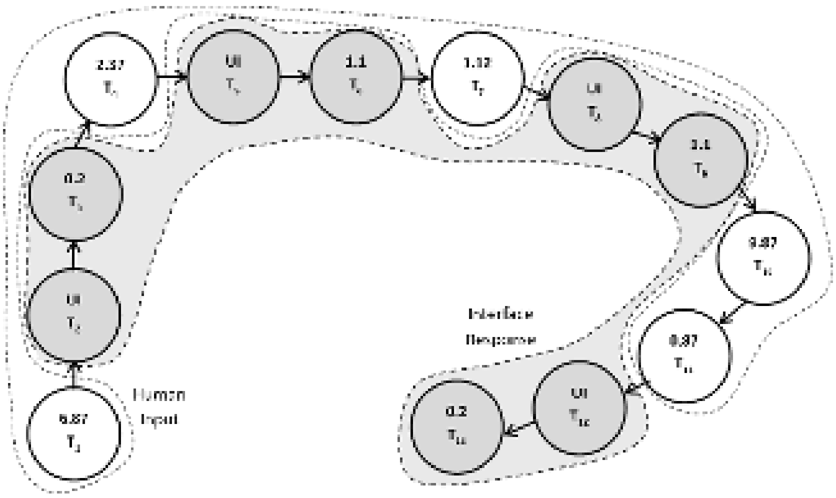

Figure 71. OS2 "go to webpage" task graph.

Table 31. OS2 "go to webpage" subtask complexities.

Task	Go To Webpage	Average
1	Click on Applications	6.875
2	Response from Phone	UI
3	Response from Phone	0.2
4	Locate Browser	2.375
5	Response from Phone	UI
6	Response from Phone	1.1
7	Locate Address Area	1.125
8	Response from Phone	UI
9	Response from Phone	1.1
10	Enter Address	9.875
11	Click on Go	0.875
12	Response from Phone	UI
13	Response from Phone	0.2

Task Set:

$T = \{T_1, T_2, T_3, T_4, T_5, T_6, T_7, T_8, T_9, T_{10}, T_{11}, T_{12}, T_{13}\}$

Difficulty Set:

$\tau = \{\tau_1, \tau_2, \tau_3, \tau_4, \tau_5, \tau_6, \tau_7, \tau_8, \tau_9, \tau_{10}, \tau_{11}, \tau_{12}, \tau_{13}\}$

$\tau = \{8.875, \tau_2, 0.2, 2.375, \tau_5, 1.1, 1.125, \tau_8, 1.1, 9.875, 0.875, \tau_{12}, 0.2\}$

Data Transfer Matrix:

$$F = \begin{bmatrix} 0 & f_{12} & f_{13} & f_{14} & f_{15} & f_{16} & f_{17} & f_{18} & f_{19} & f_{110} & f_{111} & f_{112} & f_{113} \\ f_{21} & 0 & f_{23} & f_{24} & f_{25} & f_{26} & f_{27} & f_{28} & f_{29} & f_{210} & f_{211} & f_{212} & f_{213} \\ f_{31} & f_{32} & 0 & f_{34} & f_{35} & f_{36} & f_{37} & f_{38} & f_{39} & f_{310} & f_{311} & f_{312} & f_{313} \\ f_{41} & f_{42} & f_{43} & 0 & f_{45} & f_{46} & f_{47} & f_{48} & f_{49} & f_{410} & f_{411} & f_{412} & f_{413} \\ f_{51} & f_{52} & f_{53} & f_{54} & 0 & f_{56} & f_{57} & f_{58} & f_{59} & f_{510} & f_{511} & f_{512} & f_{513} \\ f_{61} & f_{62} & f_{63} & f_{64} & f_{65} & 0 & f_{67} & f_{68} & f_{69} & f_{610} & f_{611} & f_{612} & f_{613} \\ f_{71} & f_{72} & f_{73} & f_{74} & f_{75} & f_{76} & 0 & f_{78} & f_{79} & f_{710} & f_{711} & f_{712} & f_{713} \\ f_{81} & f_{82} & f_{83} & f_{84} & f_{85} & f_{86} & f_{87} & 0 & f_{89} & f_{810} & f_{811} & f_{812} & f_{813} \\ f_{91} & f_{92} & f_{93} & f_{94} & f_{95} & f_{96} & f_{97} & f_{98} & 0 & f_{910} & f_{911} & f_{912} & f_{913} \\ f_{101} & f_{102} & f_{103} & f_{104} & f_{105} & f_{106} & f_{107} & f_{108} & f_{109} & 0 & f_{1010} & f_{1011} & f_{1013} \\ f_{111} & f_{112} & f_{113} & f_{114} & f_{115} & f_{116} & f_{117} & f_{118} & f_{119} & f_{1110} & 0 & f_{1112} & f_{1113} \\ f_{121} & f_{122} & f_{123} & f_{124} & f_{125} & f_{126} & f_{127} & f_{128} & f_{129} & f_{1210} & f_{1211} & 0 & f_{1213} \\ f_{131} & f_{132} & f_{133} & f_{134} & f_{135} & f_{136} & f_{137} & f_{138} & f_{139} & f_{1310} & f_{1311} & f_{1312} & 0 \end{bmatrix}$$

$$= \begin{bmatrix} 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 11 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

Task Allocation Matrix:

$$A = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \\ a_{31} & a_{32} \\ a_{41} & a_{42} \\ a_{51} & a_{52} \\ a_{61} & a_{62} \\ a_{71} & a_{72} \\ a_{81} & a_{82} \\ a_{91} & a_{92} \\ a_{101} & a_{102} \\ a_{111} & a_{112} \\ a_{121} & a_{122} \\ a_{131} & a_{132} \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ 1 & 0 \\ 1 & 0 \\ 0 & 1 \\ 1 & 0 \\ 1 & 0 \\ 0 & 1 \\ 1 & 0 \\ 1 & 0 \\ 0 & 1 \\ 0 & 1 \\ 1 & 0 \\ 1 & 0 \end{bmatrix}$$

Using the Matlab HIQ function with the above data we get: **HIQ = 29.695;** hence **UIQ = 50 – 29.695 = 20.305**

OS3 “Make a Call” Task

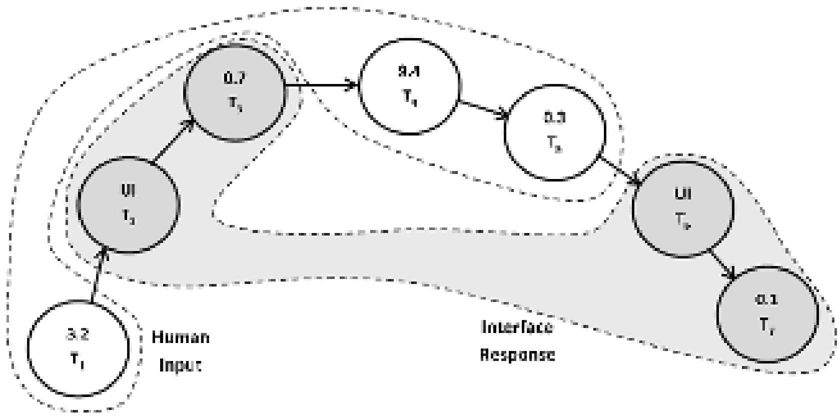

Figure 72. OS3 “make a call” task graph.

Table 32. OS3 “make a call” subtask complexities.

Task	Make a Call	Average
1	Locate Phone Application	3.2
2	Response from Phone	UI
3	Response from Phone	0.7
4	Dial Numbers	9.4
5	Click Call	0.3
6	Response from Phone	UI
7	Response from Phone	0.1

Task Set:

$T = \{T_1, T_2, T_3, T_4, T_5, T_6, T_7\}$

Difficulty Set:

$\tau = \{\tau_1, \tau_2, \tau_3, \tau_4, \tau_5, \tau_6, \tau_7\}$

$\tau = \{3.2, \tau_2, 0.7, 9.4, 0.3, \tau_6, 0.1\}$

Data Transfer Matrix:

$$F = \begin{bmatrix} 0 & f_{12} & f_{13} & f_{14} & f_{15} & f_{16} & f_{17} \\ f_{21} & 0 & f_{23} & f_{24} & f_{25} & f_{26} & f_{27} \\ f_{31} & f_{32} & 0 & f_{34} & f_{35} & f_{36} & f_{37} \\ f_{41} & f_{42} & f_{43} & 0 & f_{45} & f_{46} & f_{47} \\ f_{51} & f_{52} & f_{53} & f_{54} & 0 & f_{56} & f_{57} \\ f_{61} & f_{62} & f_{63} & f_{64} & f_{65} & 0 & f_{67} \\ f_{71} & f_{72} & f_{73} & f_{74} & f_{75} & f_{76} & 0 \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 11 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

Task Allocation Matrix:

$$A = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \\ a_{31} & a_{32} \\ a_{41} & a_{42} \\ a_{51} & a_{52} \\ a_{61} & a_{62} \\ a_{71} & a_{72} \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ 1 & 0 \\ 1 & 1 \\ 0 & 1 \\ 0 & 1 \\ 1 & 0 \\ 1 & 0 \end{bmatrix}$$

Using the Matlab HIQ function with the above data we get: **HIQ = 16.752;** hence **UIQ = 50 – 16.752 = 33.248**

OS3 "Send a Message" Task

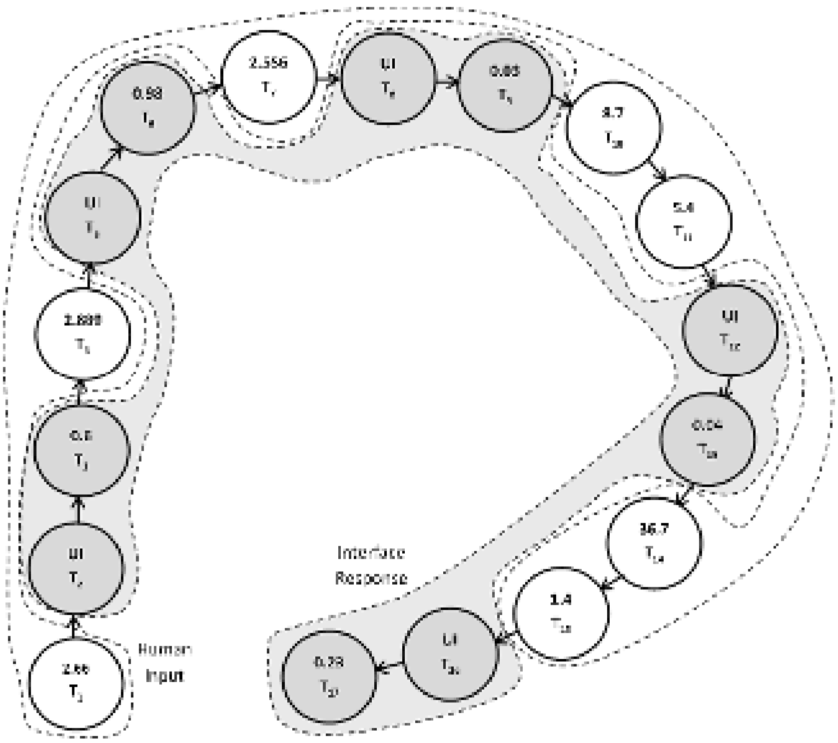

Figure 73. OS3 "send a message" task graph.

Table 33. OS3 "send a message" subtask complexities.

Task	Send SMS	Average
1	Locate Messaging Application	2.666667
2	Response from Phone	UI
3	Response from Phone	0.6
4	Select new message	2.888889
5	Response from Phone	UI
6	Response from Phone	0.98
7	Select Digit view	2.555556
8	Response from Phone	UI
9	Response from Phone	0.03
10	Enter numbers	8.7
11	Select Text input area	5.4
12	Response from Phone	UI
13	Response from Phone	0.04
14	Enter Text Message	36.7
15	Click Send	1.4
16	Response from Phone	UI
17	Response from Phone	0.23

Task Set:

$T = \{T_1, T_2, T_3, T_4, T_5, T_6, T_7, T_8, T_9, T_{10}, T_{11}, T_{12}, T_{13}, T_{14}, T_{15}, T_{16}, T_{17}\}$

Difficulty Set:

$\tau = \{\tau_1, \tau_2, \tau_3, \tau_4, \tau_5, \tau_6, \tau_7, \tau_8, \tau_9, \tau_{10}, \tau_{11}, \tau_{12}, \tau_{13}, \tau_{14}, \tau_{15}, \tau_{16}, \tau_{17}\}$

$\tau = \{2.667, \tau_2, 0.6, 2.889, \tau_5, 0.98, 2.556, \tau_8, 0.03, 8.7, 5.4, \tau_{12}, 0.04, 36.7, 1.4, \tau_{16}, 0.23\}$

Data Transfer Matrix:

$$F = \begin{bmatrix}
0 & f_{12} & f_{13} & f_{14} & f_{15} & f_{16} & f_{17} & f_{18} & f_{19} & f_{110} & f_{111} & f_{112} & f_{113} & f_{114} & f_{115} & f_{116} & f_{117} \\
f_{21} & 0 & f_{23} & f_{24} & f_{25} & f_{26} & f_{27} & f_{28} & f_{29} & f_{210} & f_{211} & f_{212} & f_{213} & f_{214} & f_{215} & f_{216} & f_{217} \\
f_{31} & f_{32} & 0 & f_{34} & f_{35} & f_{36} & f_{37} & f_{38} & f_{39} & f_{310} & f_{311} & f_{312} & f_{313} & f_{314} & f_{315} & f_{316} & f_{317} \\
f_{41} & f_{42} & f_{43} & 0 & f_{45} & f_{46} & f_{47} & f_{48} & f_{49} & f_{410} & f_{411} & f_{412} & f_{413} & f_{414} & f_{415} & f_{416} & f_{417} \\
f_{51} & f_{52} & f_{53} & f_{54} & 0 & f_{56} & f_{57} & f_{58} & f_{59} & f_{510} & f_{511} & f_{512} & f_{513} & f_{514} & f_{515} & f_{516} & f_{517} \\
f_{61} & f_{62} & f_{63} & f_{64} & f_{65} & 0 & f_{67} & f_{68} & f_{69} & f_{610} & f_{611} & f_{612} & f_{613} & f_{614} & f_{615} & f_{616} & f_{617} \\
f_{71} & f_{72} & f_{73} & f_{74} & f_{75} & f_{76} & 0 & f_{78} & f_{79} & f_{710} & f_{711} & f_{712} & f_{713} & f_{714} & f_{715} & f_{716} & f_{717} \\
f_{81} & f_{82} & f_{83} & f_{84} & f_{85} & f_{86} & f_{87} & 0 & f_{89} & f_{810} & f_{811} & f_{812} & f_{813} & f_{814} & f_{815} & f_{816} & f_{817} \\
f_{91} & f_{92} & f_{93} & f_{94} & f_{95} & f_{96} & f_{97} & f_{98} & 0 & f_{910} & f_{911} & f_{912} & f_{913} & f_{914} & f_{915} & f_{916} & f_{917} \\
f_{101} & f_{102} & f_{103} & f_{104} & f_{105} & f_{106} & f_{107} & f_{108} & f_{109} & 0 & f_{1010} & f_{1011} & f_{1013} & f_{1014} & f_{1015} & f_{1016} & f_{1017} \\
f_{111} & f_{112} & f_{113} & f_{114} & f_{115} & f_{116} & f_{117} & f_{118} & f_{119} & f_{1110} & 0 & f_{1112} & f_{1113} & f_{1114} & f_{1115} & f_{1116} & f_{1117} \\
f_{121} & f_{122} & f_{123} & f_{124} & f_{125} & f_{126} & f_{127} & f_{128} & f_{129} & f_{1210} & f_{1211} & 0 & f_{1213} & f_{1214} & f_{1215} & f_{1216} & f_{1217} \\
f_{131} & f_{132} & f_{133} & f_{134} & f_{135} & f_{136} & f_{137} & f_{138} & f_{139} & f_{1310} & f_{1311} & f_{1312} & 0 & f_{1314} & f_{1315} & f_{1316} & f_{1317} \\
f_{141} & f_{142} & f_{143} & f_{144} & f_{145} & f_{146} & f_{147} & f_{148} & f_{149} & f_{1410} & f_{1411} & f_{1412} & f_{1413} & 0 & f_{1415} & f_{1416} & f_{1417} \\
f_{151} & f_{152} & f_{153} & f_{154} & f_{155} & f_{156} & f_{157} & f_{158} & f_{159} & f_{1510} & f_{1511} & f_{1512} & f_{1513} & f_{1514} & 0 & f_{1516} & f_{1517} \\
f_{161} & f_{162} & f_{163} & f_{164} & f_{165} & f_{166} & f_{167} & f_{168} & f_{169} & f_{1610} & f_{1611} & f_{1612} & f_{1613} & f_{1614} & f_{1615} & 0 & f_{1617} \\
f_{171} & f_{172} & f_{173} & f_{174} & f_{175} & f_{176} & f_{177} & f_{178} & f_{179} & f_{1710} & f_{1711} & f_{1712} & f_{1713} & f_{1714} & f_{1715} & f_{1716} & 0
\end{bmatrix}$$

$$= \begin{bmatrix}
0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
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0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
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0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0
\end{bmatrix}$$

Task Allocation Matrix:

$$A = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \\ a_{31} & a_{32} \\ a_{41} & a_{42} \\ a_{51} & a_{52} \\ a_{61} & a_{62} \\ a_{71} & a_{72} \\ a_{81} & a_{82} \\ a_{91} & a_{92} \\ a_{101} & a_{102} \\ a_{111} & a_{112} \\ a_{121} & a_{122} \\ a_{131} & a_{132} \\ a_{141} & a_{142} \\ a_{151} & a_{152} \\ a_{161} & a_{162} \\ a_{171} & a_{172} \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ 1 & 0 \\ 1 & 0 \\ 0 & 1 \\ 1 & 0 \\ 1 & 0 \\ 0 & 1 \\ 1 & 0 \\ 1 & 0 \\ 0 & 1 \\ 0 & 1 \\ 1 & 0 \\ 1 & 0 \\ 0 & 1 \\ 0 & 1 \\ 1 & 0 \\ 1 & 0 \end{bmatrix}$$

Using the Matlab HIQ function with the above data we get: **HIQ = 76.464;** hence **UIQ = 200 – 76.464 = 123.536**

OS3 Set Appointment Task

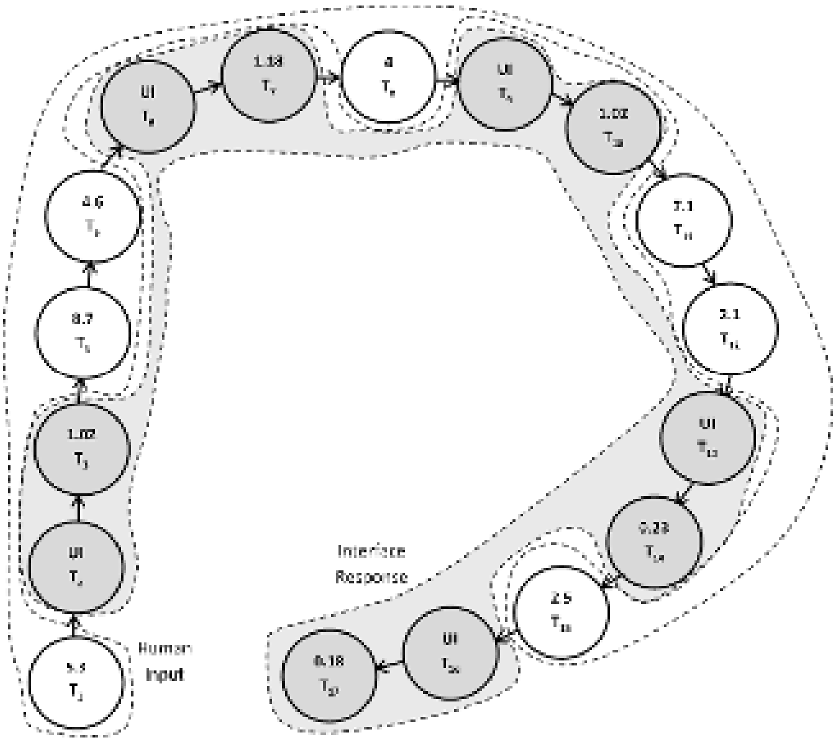

Figure 74. OS3 "set appointment" task graph.

Table 34. OS3 "set appointment" subtask complexities.

Task	Set Appointment	Average
1	Locate Calendar Application	5.3
2	Response from Phone	UI
3	Response from Phone	1.02
4	Locate Date	8.7
5	Click Add	4.6
6	Response from Phone	UI
7	Response from Phone	1.18
8	Click Title Area	4
9	Response from Phone	UI
10	Response from Phone	1.02
11	Type Name of Appointment	7.1
12	Click Done	2.1
13	Response from Phone	UI
14	Response from Phone	0.23
15	Click Done	2.5
16	Response from Phone	UI
17	Response from Phone	0.18

Task Set:

$T = \{T_1, T_2, T_3, T_4, T_5, T_6, T_7, T_8, T_9, T_{10}, T_{11}, T_{12}, T_{13}, T_{14}, T_{15}, T_{16}, T_{17}\}$

Difficulty Set:

$\tau = \{\tau_1, \tau_2, \tau_3, \tau_4, \tau_5, \tau_6, \tau_7, \tau_8, \tau_9, \tau_{10}, \tau_{11}, \tau_{12}, \tau_{13}, \tau_{14}, \tau_{15}, \tau_{16}, \tau_{17}\}$

$\tau = \{5.3, \tau_2, 1.02, 8.7, 4.6, \tau_6, 1.18, 4, \tau_9, 1.02, 7.1, 2.1, \tau_{13}, 0.23, 2.5, \tau_{16}, 0.18\}$

Data Transfer Matrix:

$$F = \begin{bmatrix}
0 & f_{12} & f_{13} & f_{14} & f_{15} & f_{16} & f_{17} & f_{18} & f_{19} & f_{110} & f_{111} & f_{112} & f_{113} & f_{114} & f_{115} & f_{116} & f_{117} \\
f_{21} & 0 & f_{23} & f_{24} & f_{25} & f_{26} & f_{27} & f_{28} & f_{29} & f_{210} & f_{211} & f_{212} & f_{213} & f_{214} & f_{215} & f_{216} & f_{217} \\
f_{31} & f_{32} & 0 & f_{34} & f_{35} & f_{36} & f_{37} & f_{38} & f_{39} & f_{310} & f_{311} & f_{312} & f_{313} & f_{314} & f_{315} & f_{316} & f_{317} \\
f_{41} & f_{42} & f_{43} & 0 & f_{45} & f_{46} & f_{47} & f_{48} & f_{49} & f_{410} & f_{411} & f_{412} & f_{413} & f_{414} & f_{415} & f_{416} & f_{417} \\
f_{51} & f_{52} & f_{53} & f_{54} & 0 & f_{56} & f_{57} & f_{58} & f_{59} & f_{510} & f_{511} & f_{512} & f_{513} & f_{514} & f_{515} & f_{516} & f_{517} \\
f_{61} & f_{62} & f_{63} & f_{64} & f_{65} & 0 & f_{67} & f_{68} & f_{69} & f_{610} & f_{611} & f_{612} & f_{613} & f_{614} & f_{615} & f_{616} & f_{617} \\
f_{71} & f_{72} & f_{73} & f_{74} & f_{75} & f_{76} & 0 & f_{78} & f_{79} & f_{710} & f_{711} & f_{712} & f_{713} & f_{714} & f_{715} & f_{716} & f_{717} \\
f_{81} & f_{82} & f_{83} & f_{84} & f_{85} & f_{86} & f_{87} & 0 & f_{89} & f_{810} & f_{811} & f_{812} & f_{813} & f_{814} & f_{815} & f_{816} & f_{817} \\
f_{91} & f_{92} & f_{93} & f_{94} & f_{95} & f_{96} & f_{97} & f_{98} & 0 & f_{910} & f_{911} & f_{912} & f_{913} & f_{914} & f_{915} & f_{916} & f_{917} \\
f_{101} & f_{102} & f_{103} & f_{104} & f_{105} & f_{106} & f_{107} & f_{108} & f_{109} & 0 & f_{1010} & f_{1011} & f_{1013} & f_{1014} & f_{1015} & f_{1016} & f_{1017} \\
f_{111} & f_{112} & f_{113} & f_{114} & f_{115} & f_{116} & f_{117} & f_{118} & f_{119} & f_{1110} & 0 & f_{1112} & f_{1113} & f_{1114} & f_{1115} & f_{1116} & f_{1117} \\
f_{121} & f_{122} & f_{123} & f_{124} & f_{125} & f_{126} & f_{127} & f_{128} & f_{129} & f_{1210} & f_{1211} & 0 & f_{1213} & f_{1214} & f_{1215} & f_{1216} & f_{1217} \\
f_{131} & f_{132} & f_{133} & f_{134} & f_{135} & f_{136} & f_{137} & f_{138} & f_{139} & f_{1310} & f_{1311} & f_{1312} & 0 & f_{1314} & f_{1315} & f_{1316} & f_{1317} \\
f_{141} & f_{142} & f_{143} & f_{144} & f_{145} & f_{146} & f_{147} & f_{148} & f_{149} & f_{1410} & f_{1411} & f_{1412} & f_{1413} & 0 & f_{1415} & f_{1416} & f_{1417} \\
f_{151} & f_{152} & f_{153} & f_{154} & f_{155} & f_{156} & f_{157} & f_{158} & f_{159} & f_{1510} & f_{1511} & f_{1512} & f_{1513} & f_{1514} & 0 & f_{1516} & f_{1517} \\
f_{161} & f_{162} & f_{163} & f_{164} & f_{165} & f_{166} & f_{167} & f_{168} & f_{169} & f_{1610} & f_{1611} & f_{1612} & f_{1613} & f_{1614} & f_{1615} & 0 & f_{1617} \\
f_{171} & f_{172} & f_{173} & f_{174} & f_{175} & f_{176} & f_{177} & f_{178} & f_{179} & f_{1710} & f_{1711} & f_{1712} & f_{1713} & f_{1714} & f_{1715} & f_{1716} & 0
\end{bmatrix}$$

$$= \begin{bmatrix}
0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 10 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
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0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0
\end{bmatrix}$$

Task Allocation Matrix:

$$A = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \\ a_{31} & a_{32} \\ a_{41} & a_{42} \\ a_{51} & a_{52} \\ a_{61} & a_{62} \\ a_{71} & a_{72} \\ a_{81} & a_{82} \\ a_{91} & a_{92} \\ a_{101} & a_{102} \\ a_{111} & a_{112} \\ a_{121} & a_{122} \\ a_{131} & a_{132} \\ a_{141} & a_{142} \\ a_{151} & a_{152} \\ a_{161} & a_{162} \\ a_{171} & a_{172} \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ 1 & 0 \\ 1 & 0 \\ 0 & 1 \\ 1 & 0 \\ 1 & 0 \\ 0 & 1 \\ 1 & 0 \\ 1 & 0 \\ 0 & 1 \\ 0 & 1 \\ 1 & 0 \\ 1 & 0 \\ 0 & 1 \\ 0 & 1 \\ 1 & 0 \\ 1 & 0 \end{bmatrix}$$

Using the Matlab HIQ function with the above data we get: **HIQ = 42.162;** hence **UIQ = 100 – 42.162 = 57.383**

OS3 “Go to Webpage” Task

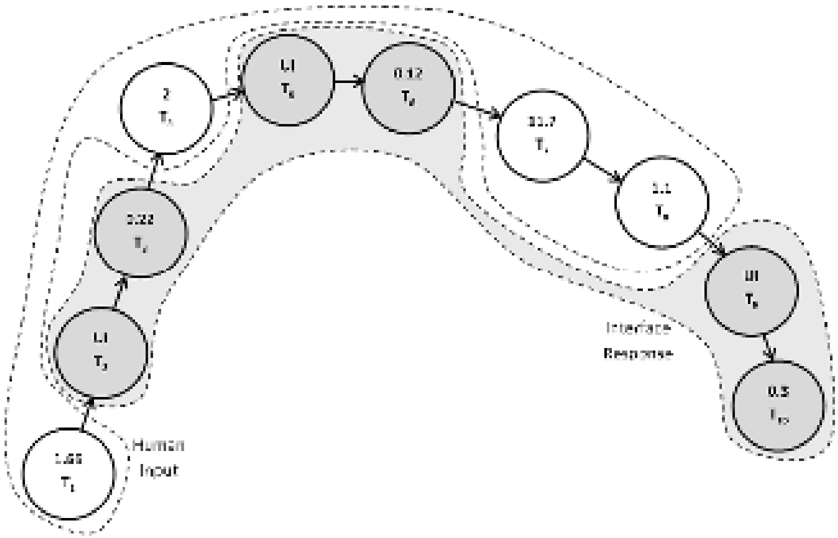

Figure 75. OS3 “go to webpage” task graph.

Table 35. OS3 "go to webpage" subtask complexities.

Task	Go To Webpage	Average
1	Locate Browser	1.666667
2	Response from Phone	UI
3	Response from Phone	0.22
4	Locate Address Area	2
5	Response from Phone	UI
6	Response from Phone	0.12
7	Enter Address	11.7
8	Click on Go	1.1
9	Response from Phone	UI
10	Response from Phone	0.3

Task Set:

$T = \{T_1, T_2, T_3, T_4, T_5, T_6, T_7, T_8, T_9, T_{10}\}$

Difficulty Set:

$\tau = \{\tau_1, \tau_2, \tau_3, \tau_4, \tau_5, \tau_6, \tau_7, \tau_8, \tau_9, \tau_{10}\}$

$\tau = \{1.667, \tau_2, 0.22, 2, \tau_5, 0.12, 11.7, 1.1, \tau_9, 0.3\}$

Data Transfer Matrix:

$$F = \begin{bmatrix} 0 & f_{12} & f_{13} & f_{14} & f_{15} & f_{16} & f_{17} & f_{18} & f_{19} & f_{110} \\ f_{21} & 0 & f_{23} & f_{24} & f_{25} & f_{26} & f_{27} & f_{28} & f_{29} & f_{210} \\ f_{31} & f_{32} & 0 & f_{34} & f_{35} & f_{36} & f_{37} & f_{38} & f_{39} & f_{310} \\ f_{41} & f_{42} & f_{43} & 0 & f_{45} & f_{46} & f_{47} & f_{48} & f_{49} & f_{410} \\ f_{51} & f_{52} & f_{53} & f_{54} & 0 & f_{56} & f_{57} & f_{58} & f_{59} & f_{510} \\ f_{61} & f_{62} & f_{63} & f_{64} & f_{65} & 0 & f_{67} & f_{68} & f_{69} & f_{610} \\ f_{71} & f_{72} & f_{73} & f_{74} & f_{75} & f_{76} & 0 & f_{78} & f_{79} & f_{710} \\ f_{81} & f_{82} & f_{83} & f_{84} & f_{85} & f_{86} & f_{87} & 0 & f_{89} & f_{810} \\ f_{91} & f_{92} & f_{93} & f_{94} & f_{95} & f_{96} & f_{97} & f_{98} & 0 & f_{910} \\ f_{101} & f_{102} & f_{103} & f_{104} & f_{105} & f_{106} & f_{107} & f_{108} & f_{109} & 0 \end{bmatrix}$$

$$= \begin{bmatrix} 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 11 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

Task Allocation Matrix:

$$A = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \\ a_{31} & a_{32} \\ a_{41} & a_{42} \\ a_{51} & a_{52} \\ a_{61} & a_{62} \\ a_{71} & a_{72} \\ a_{81} & a_{82} \\ a_{91} & a_{92} \\ a_{101} & a_{102} \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ 1 & 0 \\ 1 & 0 \\ 0 & 1 \\ 1 & 0 \\ 1 & 0 \\ 0 & 1 \\ 0 & 1 \\ 1 & 0 \\ 1 & 0 \end{bmatrix}$$

Using the Matlab HIQ function with the above data we get: **HIQ = 21.107;** hence **UIQ = 50 – 21.107= 28.893**

OS4 "Make a Call" Task

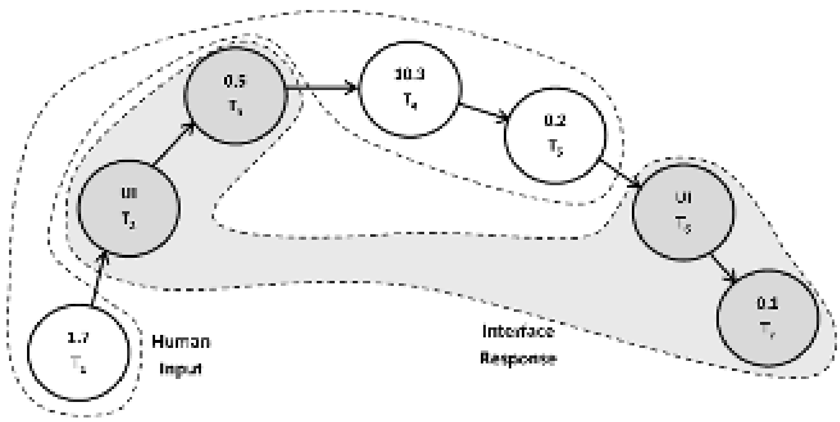

Figure 76. OS4 "make a call" task graph.

Table 36. OS4 "make a call" subtask complexities.

Task	Make a Call	Average
1	Locate Phone Application	1.7
2	Response from Phone	UI
3	Response from Phone	0.5
4	Dial Numbers	10.3
5	Click Call	0.2
6	Response from Phone	UI
7	Response from Phone	0.1

Task Set:

$T = \{T_1, T_2, T_3, T_4, T_5, T_6, T_7\}$

Difficulty Set:

$\tau = \{\tau_1, \tau_2, \tau_3, \tau_4, \tau_5, \tau_6, \tau_7\}$

τ = {1.7, τ_2, 0.5, 10.3, 0.2, τ_6, 0.1}

Data Transfer Matrix:

$$F = \begin{bmatrix} 0 & f_{12} & f_{13} & f_{14} & f_{15} & f_{16} & f_{17} \\ f_{21} & 0 & f_{23} & f_{24} & f_{25} & f_{26} & f_{27} \\ f_{31} & f_{32} & 0 & f_{34} & f_{35} & f_{36} & f_{37} \\ f_{41} & f_{42} & f_{43} & 0 & f_{45} & f_{46} & f_{47} \\ f_{51} & f_{52} & f_{53} & f_{54} & 0 & f_{56} & f_{57} \\ f_{61} & f_{62} & f_{63} & f_{64} & f_{65} & 0 & f_{67} \\ f_{71} & f_{72} & f_{73} & f_{74} & f_{75} & f_{76} & 0 \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 11 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

Task Allocation Matrix:

$$A = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \\ a_{31} & a_{32} \\ a_{41} & a_{42} \\ a_{51} & a_{52} \\ a_{61} & a_{62} \\ a_{71} & a_{72} \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ 1 & 0 \\ 1 & 1 \\ 0 & 1 \\ 0 & 1 \\ 1 & 0 \\ 1 & 0 \end{bmatrix}$$

Using the Matlab HIQ function with the above data we get: **HIQ = 15;** hence **UIQ = 50 – 15 = 35**

OS4 “Send a Message” Task

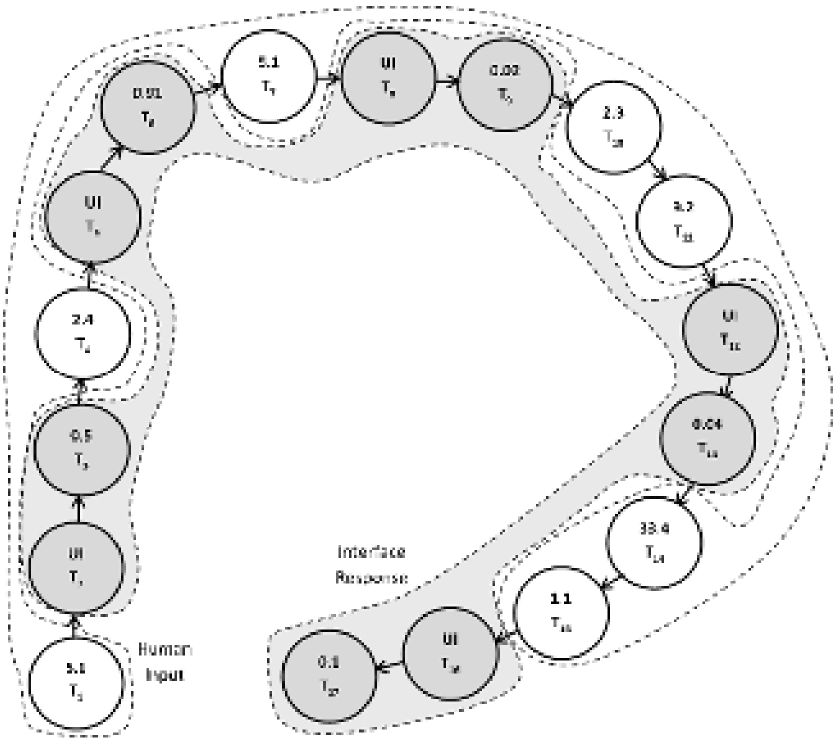

Figure 77. OS4 “send a message” task graph.

Table 37. OS4 “send a message” subtask complexities.

Task	Send SMS	Average
1	Locate Messaging Application	5.1
2	Response from Phone	UI
3	Response from Phone	0.5
4	Select new message	2.4
5	Response from Phone	UI
6	Response from Phone	0.1
7	Select Digit view	5.1
8	Response from Phone	UI
9	Response from Phone	0.02
10	Enter numbers	12.3
11	Select Text input area	3.2
12	Response from Phone	UI
13	Response from Phone	0.04
14	Enter Text Message	33.4
15	Click Send	1.1
16	Response from Phone	UI
17	Response from Phone	0.1

Task Set:

T = {T_1, T_2, T_3, T_4, T_5, T_6, T_7, T_8, T_9, T_{10}, T_{11}, T_{12}, T_{13}, T_{14}, T_{15}, T_{16}, T_{17}}

Difficulty Set:

τ = {τ_1, τ_2, τ_3, τ_4, τ_5, τ_6, τ_7, τ_8, τ_9, τ_{10}, τ_{11}, τ_{12}, τ_{13}, τ_{14}, τ_{15}, τ_{16}, τ_{17}}

τ = {5.1, τ_2, 0.5, 2.4, τ_5, 0.1, 5.1, τ_8, 0.02, 12.3, 3.2, τ_{12}, 0.04, 33.4, 1.1, τ_{16}, 0.1}

Data Transfer Matrix:

$$F = \begin{bmatrix}
0 & f_{12} & f_{13} & f_{14} & f_{15} & f_{16} & f_{17} & f_{18} & f_{19} & f_{110} & f_{111} & f_{112} & f_{113} & f_{114} & f_{115} & f_{116} & f_{117} \\
f_{21} & 0 & f_{23} & f_{24} & f_{25} & f_{26} & f_{27} & f_{28} & f_{29} & f_{210} & f_{211} & f_{212} & f_{213} & f_{214} & f_{215} & f_{216} & f_{217} \\
f_{31} & f_{32} & 0 & f_{34} & f_{35} & f_{36} & f_{37} & f_{38} & f_{39} & f_{310} & f_{311} & f_{312} & f_{313} & f_{314} & f_{315} & f_{316} & f_{317} \\
f_{41} & f_{42} & f_{43} & 0 & f_{45} & f_{46} & f_{47} & f_{48} & f_{49} & f_{410} & f_{411} & f_{412} & f_{413} & f_{414} & f_{415} & f_{416} & f_{417} \\
f_{51} & f_{52} & f_{53} & f_{54} & 0 & f_{56} & f_{57} & f_{58} & f_{59} & f_{510} & f_{511} & f_{512} & f_{513} & f_{514} & f_{515} & f_{516} & f_{517} \\
f_{61} & f_{62} & f_{63} & f_{64} & f_{65} & 0 & f_{67} & f_{68} & f_{69} & f_{610} & f_{611} & f_{612} & f_{613} & f_{614} & f_{615} & f_{616} & f_{617} \\
f_{71} & f_{72} & f_{73} & f_{74} & f_{75} & f_{76} & 0 & f_{78} & f_{79} & f_{710} & f_{711} & f_{712} & f_{713} & f_{714} & f_{715} & f_{716} & f_{717} \\
f_{81} & f_{82} & f_{83} & f_{84} & f_{85} & f_{86} & f_{87} & 0 & f_{89} & f_{810} & f_{811} & f_{812} & f_{813} & f_{814} & f_{815} & f_{816} & f_{817} \\
f_{91} & f_{92} & f_{93} & f_{94} & f_{95} & f_{96} & f_{97} & f_{98} & 0 & f_{910} & f_{911} & f_{912} & f_{913} & f_{914} & f_{915} & f_{916} & f_{917} \\
f_{101} & f_{102} & f_{103} & f_{104} & f_{105} & f_{106} & f_{107} & f_{108} & f_{109} & 0 & f_{1010} & f_{1011} & f_{1013} & f_{1014} & f_{1015} & f_{1016} & f_{1017} \\
f_{111} & f_{112} & f_{113} & f_{114} & f_{115} & f_{116} & f_{117} & f_{118} & f_{119} & f_{1110} & 0 & f_{1112} & f_{1113} & f_{1114} & f_{1115} & f_{1116} & f_{1117} \\
f_{121} & f_{122} & f_{123} & f_{124} & f_{125} & f_{126} & f_{127} & f_{128} & f_{129} & f_{1210} & f_{1211} & 0 & f_{1213} & f_{1214} & f_{1215} & f_{1216} & f_{1217} \\
f_{131} & f_{132} & f_{133} & f_{134} & f_{135} & f_{136} & f_{137} & f_{138} & f_{139} & f_{1310} & f_{1311} & f_{1312} & 0 & f_{1314} & f_{1315} & f_{1316} & f_{1317} \\
f_{141} & f_{142} & f_{143} & f_{144} & f_{145} & f_{146} & f_{147} & f_{148} & f_{149} & f_{1410} & f_{1411} & f_{1412} & f_{1413} & 0 & f_{1415} & f_{1416} & f_{1417} \\
f_{151} & f_{152} & f_{153} & f_{154} & f_{155} & f_{156} & f_{157} & f_{158} & f_{159} & f_{1510} & f_{1511} & f_{1512} & f_{1513} & f_{1514} & 0 & f_{1516} & f_{1517} \\
f_{161} & f_{162} & f_{163} & f_{164} & f_{165} & f_{166} & f_{167} & f_{168} & f_{169} & f_{1610} & f_{1611} & f_{1612} & f_{1613} & f_{1614} & f_{1615} & 0 & f_{1617} \\
f_{171} & f_{172} & f_{173} & f_{174} & f_{175} & f_{176} & f_{177} & f_{178} & f_{179} & f_{1710} & f_{1711} & f_{1712} & f_{1713} & f_{1714} & f_{1715} & f_{1716} & 0
\end{bmatrix}$$

$$= \begin{bmatrix}
0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 10 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 37 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0
\end{bmatrix}$$

Task Allocation Matrix:

$$A = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \\ a_{31} & a_{32} \\ a_{41} & a_{42} \\ a_{51} & a_{52} \\ a_{61} & a_{62} \\ a_{71} & a_{72} \\ a_{81} & a_{82} \\ a_{91} & a_{92} \\ a_{101} & a_{102} \\ a_{111} & a_{112} \\ a_{121} & a_{122} \\ a_{131} & a_{132} \\ a_{141} & a_{142} \\ a_{151} & a_{152} \\ a_{161} & a_{162} \\ a_{171} & a_{172} \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ 1 & 0 \\ 1 & 0 \\ 0 & 1 \\ 1 & 0 \\ 1 & 0 \\ 0 & 1 \\ 1 & 0 \\ 1 & 0 \\ 0 & 1 \\ 0 & 1 \\ 1 & 0 \\ 1 & 0 \\ 0 & 1 \\ 0 & 1 \\ 1 & 0 \\ 1 & 0 \end{bmatrix}$$

Using the Matlab HIQ function with the above data we get: **HIQ = 74.816;** hence **UIQ = 200 – 74.816 = 125.184**

OS4 "Set Appointment" Task

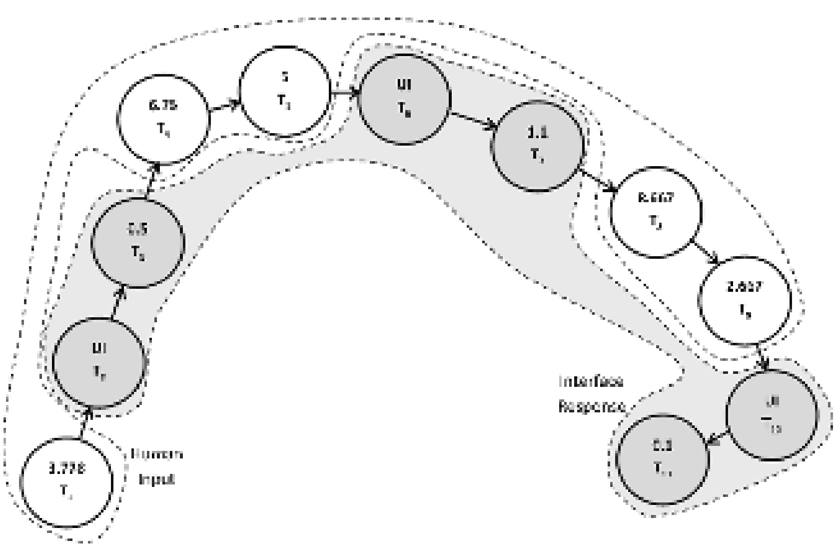

Figure 78. OS4 "set appointment" task graph.

Table 38. OS4 "set appointment" subtask complexities.

Task	Set Appointment	Average
1	Locate Calendar Application	3.777778
2	Response from Phone	UI
3	Response from Phone	0.5
4	Locate Date	6.75
5	Click Add	5
6	Response from Phone	UI
7	Response from Phone	1.1
8	Type Name of Appointment	8.666667
9	Click Done	2.666667
10	Response from Phone	UI
11	Response from Phone	0.1

Task Set:

$T = \{T_1, T_2, T_3, T_4, T_5, T_6, T_7, T_8, T_9, T_{10}, T_{11}\}$

Difficulty Set:

$\tau = \{\tau_1, \tau_2, \tau_3, \tau_4, \tau_5, \tau_6, \tau_7, \tau_8, \tau_9, \tau_{10}, \tau_{11}\}$

$\tau = \{3.778, \tau_2, 0.5, 6.75, 5, \tau_6, 1.1, 8.667, 2.667, \tau_{10}, 0.1\}$

Data Transfer Matrix:

$$F = \begin{bmatrix} 0 & f_{12} & f_{13} & f_{14} & f_{15} & f_{16} & f_{17} & f_{18} & f_{19} & f_{110} & f_{111} \\ f_{21} & 0 & f_{23} & f_{24} & f_{25} & f_{26} & f_{27} & f_{28} & f_{29} & f_{210} & f_{211} \\ f_{31} & f_{32} & 0 & f_{34} & f_{35} & f_{36} & f_{37} & f_{38} & f_{39} & f_{310} & f_{311} \\ f_{41} & f_{42} & f_{43} & 0 & f_{45} & f_{46} & f_{47} & f_{48} & f_{49} & f_{410} & f_{411} \\ f_{51} & f_{52} & f_{53} & f_{54} & 0 & f_{56} & f_{57} & f_{58} & f_{59} & f_{510} & f_{511} \\ f_{61} & f_{62} & f_{63} & f_{64} & f_{65} & 0 & f_{67} & f_{68} & f_{69} & f_{610} & f_{611} \\ f_{71} & f_{72} & f_{73} & f_{74} & f_{75} & f_{76} & 0 & f_{78} & f_{79} & f_{710} & f_{711} \\ f_{81} & f_{82} & f_{83} & f_{84} & f_{85} & f_{86} & f_{87} & 0 & f_{89} & f_{810} & f_{811} \\ f_{91} & f_{92} & f_{93} & f_{94} & f_{95} & f_{96} & f_{97} & f_{98} & 0 & f_{910} & f_{911} \\ f_{101} & f_{102} & f_{103} & f_{104} & f_{105} & f_{106} & f_{107} & f_{108} & f_{109} & 0 & f_{1011} \\ f_{111} & f_{112} & f_{113} & f_{114} & f_{115} & f_{116} & f_{117} & f_{118} & f_{119} & f_{1110} & 0 \end{bmatrix}$$

$$= \begin{bmatrix} 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 10 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 11 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

Task Allocation Matrix:

$$A = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \\ a_{31} & a_{32} \\ a_{41} & a_{42} \\ a_{51} & a_{52} \\ a_{61} & a_{62} \\ a_{71} & a_{72} \\ a_{81} & a_{82} \\ a_{91} & a_{92} \\ a_{101} & a_{102} \\ a_{111} & a_{112} \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ 1 & 0 \\ 1 & 0 \\ 0 & 1 \\ 0 & 1 \\ 1 & 0 \\ 1 & 0 \\ 0 & 1 \\ 0 & 1 \\ 1 & 0 \\ 1 & 0 \end{bmatrix}$$

Using the Matlab HIQ function with the above data we get: **HIQ = 32.92;** hence **UIQ = 100 – 32.92= 67.08**

OS4 "Go to Webpage" Task

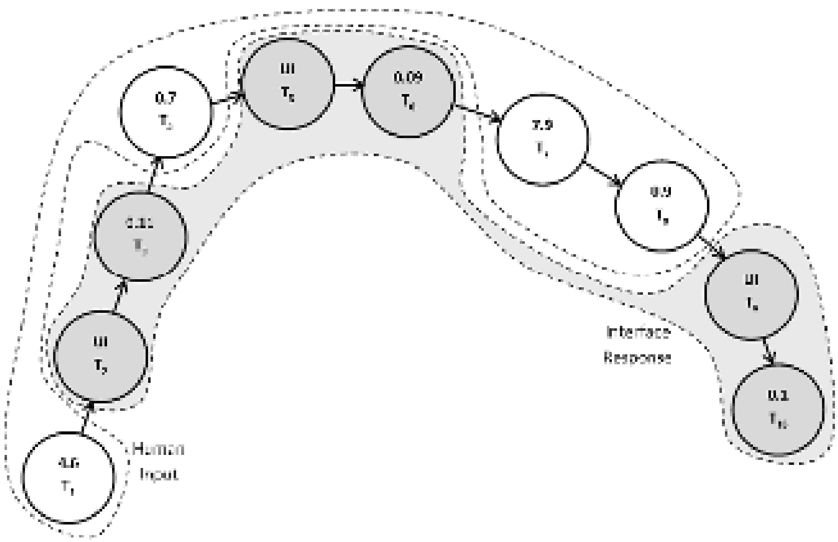

Figure 79. OS4 "go to webpage" task graph.

Table 39. OS4 go to webpage subtasks complexities.

Task	Go To Webpage	Average
1	Locate Browser	4.6
2	Response from Phone	UI
3	Response from Phone	0.11
4	Locate Address Area	0.7
5	Response from Phone	UI
6	Response from Phone	0.09
7	Enter Address	7.9
8	Click on Go	0.9
9	Response from Phone	UI
10	Response from Phone	0.1

Task Set:

$T = \{T_1, T_2, T_3, T_4, T_5, T_6, T_7, T_8, T_9, T_{10}\}$

Difficulty Set:

$\tau = \{\tau_1, \tau_2, \tau_3, \tau_4, \tau_5, \tau_6, \tau_7, \tau_8, \tau_9, \tau_{10}\}$

$\tau = \{1.667, \tau_2, 0.22, 2, \tau_5, 0.12, 11.7, 1.1, \tau_9, 0.3\}$

Data Transfer Matrix:

$$F = \begin{bmatrix} 0 & f_{12} & f_{13} & f_{14} & f_{15} & f_{16} & f_{17} & f_{18} & f_{19} & f_{110} \\ f_{21} & 0 & f_{23} & f_{24} & f_{25} & f_{26} & f_{27} & f_{28} & f_{29} & f_{210} \\ f_{31} & f_{32} & 0 & f_{34} & f_{35} & f_{36} & f_{37} & f_{38} & f_{39} & f_{310} \\ f_{41} & f_{42} & f_{43} & 0 & f_{45} & f_{46} & f_{47} & f_{48} & f_{49} & f_{410} \\ f_{51} & f_{52} & f_{53} & f_{54} & 0 & f_{56} & f_{57} & f_{58} & f_{59} & f_{510} \\ f_{61} & f_{62} & f_{63} & f_{64} & f_{65} & 0 & f_{67} & f_{68} & f_{69} & f_{610} \\ f_{71} & f_{72} & f_{73} & f_{74} & f_{75} & f_{76} & 0 & f_{78} & f_{79} & f_{710} \\ f_{81} & f_{82} & f_{83} & f_{84} & f_{85} & f_{86} & f_{87} & 0 & f_{89} & f_{810} \\ f_{91} & f_{92} & f_{93} & f_{94} & f_{95} & f_{96} & f_{97} & f_{98} & 0 & f_{910} \\ f_{101} & f_{102} & f_{103} & f_{104} & f_{105} & f_{106} & f_{107} & f_{108} & f_{109} & 0 \end{bmatrix}$$

$$= \begin{bmatrix} 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 11 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

Task Allocation Matrix:

$$A = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \\ a_{31} & a_{32} \\ a_{41} & a_{42} \\ a_{51} & a_{52} \\ a_{61} & a_{62} \\ a_{71} & a_{72} \\ a_{81} & a_{82} \\ a_{91} & a_{92} \\ a_{101} & a_{102} \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ 1 & 0 \\ 1 & 0 \\ 0 & 1 \\ 1 & 0 \\ 1 & 0 \\ 0 & 1 \\ 0 & 1 \\ 1 & 0 \\ 1 & 0 \end{bmatrix}$$

Using the Matlab HIQ function with the above data we get: **HIQ = 17.658;** hence **UIQ = 50 – 17.658 = 32.342**

OS5 “Make a Call” Task

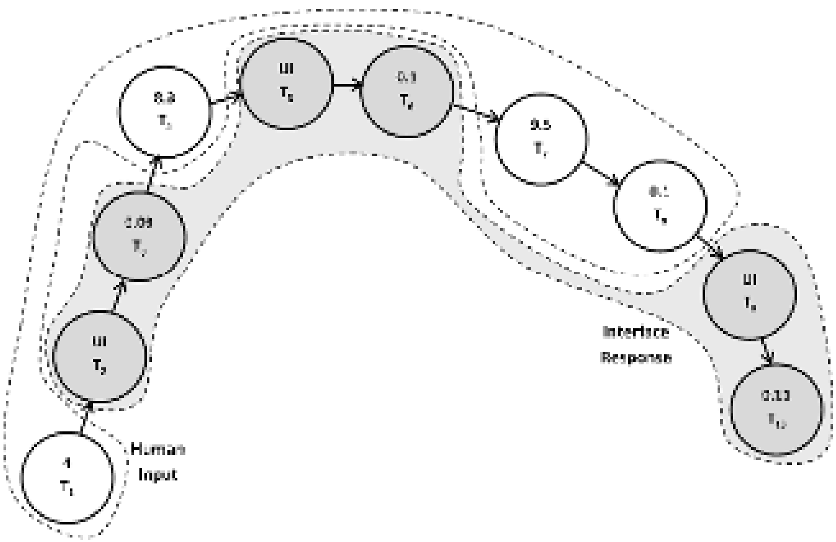

Figure 80. OS5 “make a call” task graph.

Table 40. OS5 “make a call” subtask complexities.

Task	Make a Call	Average
1	Locate Phone Application	4
2	Response from Phone	UI
3	Response from Phone	0.09
4	Click Keypad	8.3
5	Response from Phone	UI
6	Response from Phone	0.1
7	Dial Numbers	9.5
8	Click Call	0.1
9	Response from Phone	UI
10	Response from Phone	0.11

Task Set:

$T = \{T_1, T_2, T_3, T_4, T_5, T_6, T_7, T_8, T_9, T_{10}\}$

Difficulty Set:

$\tau = \{\tau_1, \tau_2, \tau_3, \tau_4, \tau_5, \tau_6, \tau_7, \tau_8, \tau_9, \tau_{10}\}$

$\tau = \{4, \tau_2, 0.09, 8.3, \tau_5, 0.1, 9.5, 0.1, \tau_9, 0.11\}$

Data Transfer Matrix:

$$F = \begin{bmatrix} 0 & f_{12} & f_{13} & f_{14} & f_{15} & f_{16} & f_{17} & f_{18} & f_{19} & f_{110} \\ f_{21} & 0 & f_{23} & f_{24} & f_{25} & f_{26} & f_{27} & f_{28} & f_{29} & f_{210} \\ f_{31} & f_{32} & 0 & f_{34} & f_{35} & f_{36} & f_{37} & f_{38} & f_{39} & f_{310} \\ f_{41} & f_{42} & f_{43} & 0 & f_{45} & f_{46} & f_{47} & f_{48} & f_{49} & f_{410} \\ f_{51} & f_{52} & f_{53} & f_{54} & 0 & f_{56} & f_{57} & f_{58} & f_{59} & f_{510} \\ f_{61} & f_{62} & f_{63} & f_{64} & f_{65} & 0 & f_{67} & f_{68} & f_{69} & f_{610} \\ f_{71} & f_{72} & f_{73} & f_{74} & f_{75} & f_{76} & 0 & f_{78} & f_{79} & f_{710} \\ f_{81} & f_{82} & f_{83} & f_{84} & f_{85} & f_{86} & f_{87} & 0 & f_{89} & f_{810} \\ f_{91} & f_{92} & f_{93} & f_{94} & f_{95} & f_{96} & f_{97} & f_{98} & 0 & f_{910} \\ f_{101} & f_{102} & f_{103} & f_{104} & f_{105} & f_{106} & f_{107} & f_{108} & f_{109} & 0 \end{bmatrix}$$

$$= \begin{bmatrix} 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 11 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

Task Allocation Matrix:

$$A = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \\ a_{31} & a_{32} \\ a_{41} & a_{42} \\ a_{51} & a_{52} \\ a_{61} & a_{62} \\ a_{71} & a_{72} \\ a_{81} & a_{82} \\ a_{91} & a_{92} \\ a_{101} & a_{102} \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ 1 & 0 \\ 1 & 0 \\ 0 & 1 \\ 1 & 0 \\ 1 & 0 \\ 0 & 1 \\ 0 & 1 \\ 1 & 0 \\ 1 & 0 \end{bmatrix}$$

Using the Matlab HIQ function with the above data we get: **HIQ = 25.128;** hence **UIQ = 50 – 25.128 = 24.872**

OS5 "Send a Message" Task

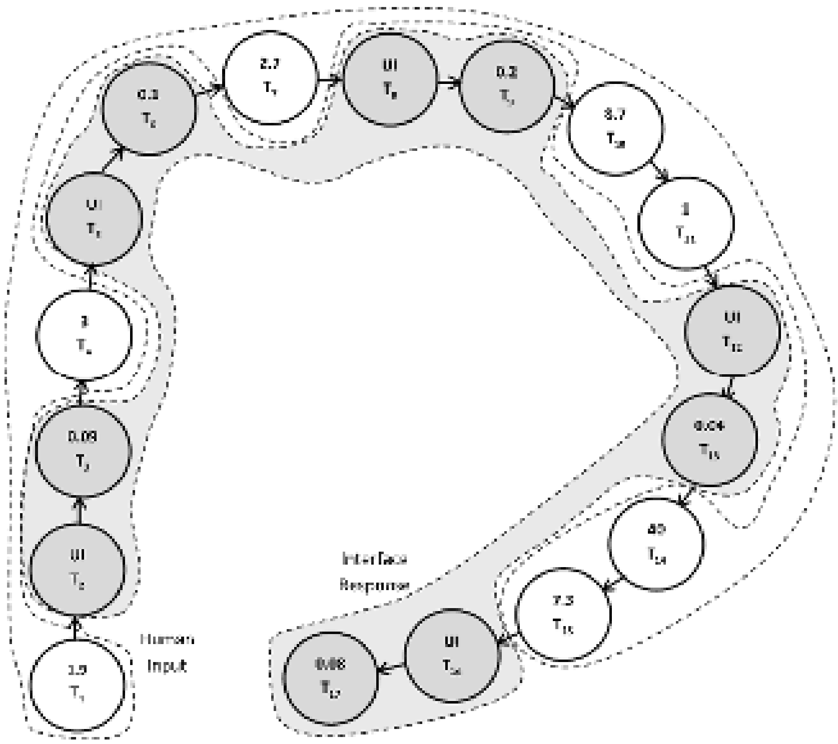

Figure 81. OS5 "send a message" task graph.

Table 41. OS5 "send a message" subtask complexities.

Task	Send SMS	Average
1	Locate Messaging Application	1.9
2	Response from Phone	UI
3	Response from Phone	0.09
4	Select new message	3
5	Response from Phone	UI
6	Response from Phone	0.1
7	Select Digit view	2.7
8	Response from Phone	UI
9	Response from Phone	0.2
10	Enter numbers	8.7
11	Select Text input area	1
12	Response from Phone	UI
13	Response from Phone	0.04
14	Enter Text Message	40
15	Click Send	7.3
16	Response from Phone	UI
17	Response from Phone	0.08

Task Set:

$T = \{T_1, T_2, T_3, T_4, T_5, T_6, T_7, T_8, T_9, T_{10}, T_{11}, T_{12}, T_{13}, T_{14}, T_{15}, T_{16}, T_{17}\}$

Difficulty Set:

$\tau = \{\tau_1, \tau_2, \tau_3, \tau_4, \tau_5, \tau_6, \tau_7, \tau_8, \tau_9, \tau_{10}, \tau_{11}, \tau_{12}, \tau_{13}, \tau_{14}, \tau_{15}, \tau_{16}, \tau_{17}\}$

$\tau = \{1.9, \tau_2, 0.09, 3, \tau_5, 0.1, 2.7, \tau_8, 0.2, 8.7, 1, \tau_{12}, 0.04, 40, 7.3, \tau_{16}, 0.08\}$

Data Transfer Matrix:

$$F = \begin{bmatrix}
0 & f_{12} & f_{13} & f_{14} & f_{15} & f_{16} & f_{17} & f_{18} & f_{19} & f_{110} & f_{111} & f_{112} & f_{113} & f_{114} & f_{115} & f_{116} & f_{117} \\
f_{21} & 0 & f_{23} & f_{24} & f_{25} & f_{26} & f_{27} & f_{28} & f_{29} & f_{210} & f_{211} & f_{212} & f_{213} & f_{214} & f_{215} & f_{216} & f_{217} \\
f_{31} & f_{32} & 0 & f_{34} & f_{35} & f_{36} & f_{37} & f_{38} & f_{39} & f_{310} & f_{311} & f_{312} & f_{313} & f_{314} & f_{315} & f_{316} & f_{317} \\
f_{41} & f_{42} & f_{43} & 0 & f_{45} & f_{46} & f_{47} & f_{48} & f_{49} & f_{410} & f_{411} & f_{412} & f_{413} & f_{414} & f_{415} & f_{416} & f_{417} \\
f_{51} & f_{52} & f_{53} & f_{54} & 0 & f_{56} & f_{57} & f_{58} & f_{59} & f_{510} & f_{511} & f_{512} & f_{513} & f_{514} & f_{515} & f_{516} & f_{517} \\
f_{61} & f_{62} & f_{63} & f_{64} & f_{65} & 0 & f_{67} & f_{68} & f_{69} & f_{610} & f_{611} & f_{612} & f_{613} & f_{614} & f_{615} & f_{616} & f_{617} \\
f_{71} & f_{72} & f_{73} & f_{74} & f_{75} & f_{76} & 0 & f_{78} & f_{79} & f_{710} & f_{711} & f_{712} & f_{713} & f_{714} & f_{715} & f_{716} & f_{717} \\
f_{81} & f_{82} & f_{83} & f_{84} & f_{85} & f_{86} & f_{87} & 0 & f_{89} & f_{810} & f_{811} & f_{812} & f_{813} & f_{814} & f_{815} & f_{816} & f_{817} \\
f_{91} & f_{92} & f_{93} & f_{94} & f_{95} & f_{96} & f_{97} & f_{98} & 0 & f_{910} & f_{911} & f_{912} & f_{913} & f_{914} & f_{915} & f_{916} & f_{917} \\
f_{101} & f_{102} & f_{103} & f_{104} & f_{105} & f_{106} & f_{107} & f_{108} & f_{109} & 0 & f_{1010} & f_{1011} & f_{1013} & f_{1014} & f_{1015} & f_{1016} & f_{1017} \\
f_{111} & f_{112} & f_{113} & f_{114} & f_{115} & f_{116} & f_{117} & f_{118} & f_{119} & f_{1110} & 0 & f_{1112} & f_{1113} & f_{1114} & f_{1115} & f_{1116} & f_{1117} \\
f_{121} & f_{122} & f_{123} & f_{124} & f_{125} & f_{126} & f_{127} & f_{128} & f_{129} & f_{1210} & f_{1211} & 0 & f_{1213} & f_{1214} & f_{1215} & f_{1216} & f_{1217} \\
f_{131} & f_{132} & f_{133} & f_{134} & f_{135} & f_{136} & f_{137} & f_{138} & f_{139} & f_{1310} & f_{1311} & f_{1312} & 0 & f_{1314} & f_{1315} & f_{1316} & f_{1317} \\
f_{141} & f_{142} & f_{143} & f_{144} & f_{145} & f_{146} & f_{147} & f_{148} & f_{149} & f_{1410} & f_{1411} & f_{1412} & f_{1413} & 0 & f_{1415} & f_{1416} & f_{1417} \\
f_{151} & f_{152} & f_{153} & f_{154} & f_{155} & f_{156} & f_{157} & f_{158} & f_{159} & f_{1510} & f_{1511} & f_{1512} & f_{1513} & f_{1514} & 0 & f_{1516} & f_{1517} \\
f_{161} & f_{162} & f_{163} & f_{164} & f_{165} & f_{166} & f_{167} & f_{168} & f_{169} & f_{1610} & f_{1611} & f_{1612} & f_{1613} & f_{1614} & f_{1615} & 0 & f_{1617} \\
f_{171} & f_{172} & f_{173} & f_{174} & f_{175} & f_{176} & f_{177} & f_{178} & f_{179} & f_{1710} & f_{1711} & f_{1712} & f_{1713} & f_{1714} & f_{1715} & f_{1716} & 0
\end{bmatrix}$$

$$= \begin{bmatrix}
0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 10 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 37 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0
\end{bmatrix}$$

Task Allocation Matrix:

$$A = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \\ a_{31} & a_{32} \\ a_{41} & a_{42} \\ a_{51} & a_{52} \\ a_{61} & a_{62} \\ a_{71} & a_{72} \\ a_{81} & a_{82} \\ a_{91} & a_{92} \\ a_{101} & a_{102} \\ a_{111} & a_{112} \\ a_{121} & a_{122} \\ a_{131} & a_{132} \\ a_{141} & a_{142} \\ a_{151} & a_{152} \\ a_{161} & a_{162} \\ a_{171} & a_{172} \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ 1 & 0 \\ 1 & 0 \\ 0 & 1 \\ 1 & 0 \\ 1 & 0 \\ 0 & 1 \\ 1 & 0 \\ 1 & 0 \\ 0 & 1 \\ 0 & 1 \\ 1 & 0 \\ 1 & 0 \\ 0 & 1 \\ 0 & 1 \\ 1 & 0 \\ 1 & 0 \end{bmatrix}$$

Using the Matlab HIQ function with the above data we get: **HIQ = 75.632;** hence **UIQ = 200 – 75.632 = 124.368**

OS5 “Set Appointment” Task

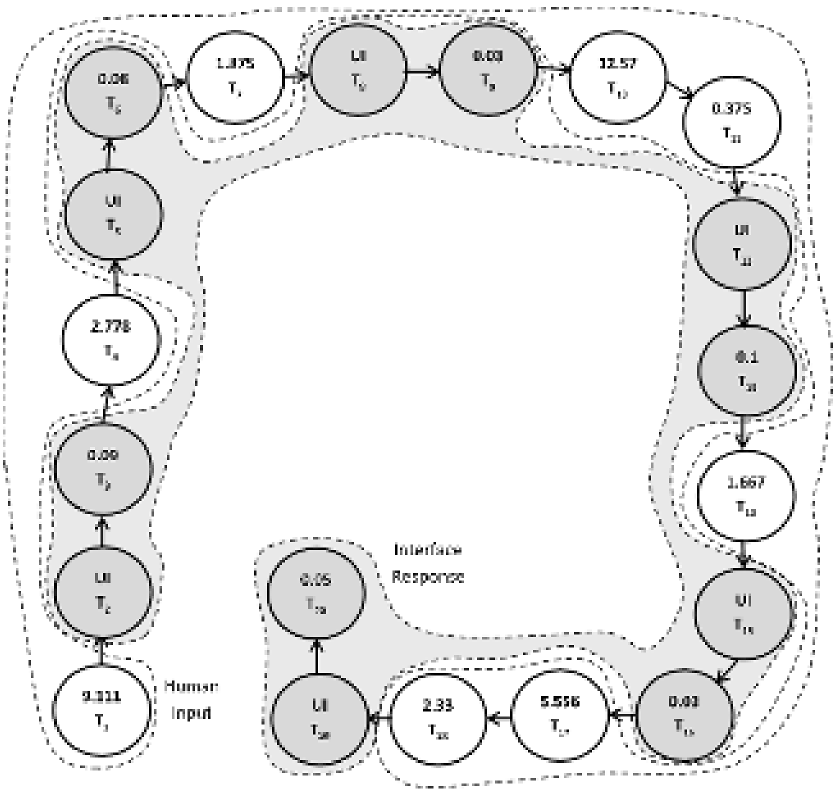

Figure 82. OS5 “set appointment” task graph.

Table 42. OS5 "set appointment" subtask complexities.

Task	Set Appointment	Average
1	Locate Calendar Application	9.111111
2	Response from Phone	UI
3	Response from Phone	0.09
4	Click Add	2.777778
5	Response from Phone	UI
6	Response from Phone	0.08
7	Click Date Area	1.875
8	Response from Phone	UI
9	Response from Phone	0.03
10	Set Date	12.57143
11	Click Accept	0.375
12	Response from Phone	UI
13	Response from Phone	0.1
14	Click Event Title area	1.666667
15	Response from Phone	UI
16	Response from Phone	0.03
17	Enter Event Name	5.555556
18	Click Save	2.333333
19	Response from Phone	UI
20	Response from Phone	0.05

Task Set:

$T = \{T_1, T_2, T_3, T_4, T_5, T_6, T_7, T_8, T_9, T_{10}, T_{11}, T_{12}, T_{13}, T_{14}, T_{15}, T_{16}, T_{17}, T_{18}, T_{19}, T_{20}\}$

Difficulty Set:

$\tau = \{\tau_1, \tau_2, \tau_3, \tau_4, \tau_5, \tau_6, \tau_7, \tau_8, \tau_9, \tau_{10}, \tau_{11}, \tau_{12}, \tau_{13}, \tau_{14}, \tau_{15}, \tau_{16}, \tau_{17}, \tau_{18}, \tau_{19}, \tau_{20}\}$

$\tau = \{9.11, \tau_2, 0.9, 2.778, \tau_5, 0.08, 1.875, \tau_8, 0.03, 12.571, 0.375, \tau_{12}, 0.1, 1.667, \tau_{15}, 0.3, 5.556, 2.333, \tau_{19}, 0.05\}$

Data Transfer Matrix:

$$F=\begin{bmatrix}
0 & f_{12} & f_{13} & f_{14} & f_{15} & f_{16} & f_{17} & f_{18} & f_{19} & f_{110} & f_{111} & f_{112} & f_{113} & f_{114} & f_{115} & f_{116} & f_{117} & f_{118} & f_{119} & f_{120}\\
f_{21} & 0 & f_{23} & f_{24} & f_{25} & f_{26} & f_{27} & f_{28} & f_{29} & f_{210} & f_{211} & f_{212} & f_{213} & f_{214} & f_{215} & f_{216} & f_{217} & f_{218} & f_{219} & f_{220}\\
f_{31} & f_{32} & 0 & f_{34} & f_{35} & f_{36} & f_{37} & f_{38} & f_{39} & f_{310} & f_{311} & f_{312} & f_{313} & f_{314} & f_{315} & f_{316} & f_{317} & f_{318} & f_{319} & f_{320}\\
f_{41} & f_{42} & f_{43} & 0 & f_{45} & f_{46} & f_{47} & f_{48} & f_{49} & f_{410} & f_{411} & f_{412} & f_{413} & f_{414} & f_{415} & f_{416} & f_{417} & f_{418} & f_{419} & f_{420}\\
f_{51} & f_{52} & f_{53} & f_{54} & 0 & f_{56} & f_{57} & f_{58} & f_{59} & f_{510} & f_{511} & f_{512} & f_{513} & f_{514} & f_{515} & f_{516} & f_{517} & f_{518} & f_{519} & f_{520}\\
f_{61} & f_{62} & f_{63} & f_{64} & f_{65} & 0 & f_{67} & f_{68} & f_{69} & f_{610} & f_{611} & f_{612} & f_{613} & f_{614} & f_{615} & f_{616} & f_{617} & f_{618} & f_{619} & f_{620}\\
f_{71} & f_{72} & f_{73} & f_{74} & f_{75} & f_{76} & 0 & f_{78} & f_{79} & f_{710} & f_{711} & f_{712} & f_{713} & f_{714} & f_{715} & f_{716} & f_{717} & f_{718} & f_{719} & f_{720}\\
f_{81} & f_{82} & f_{83} & f_{84} & f_{85} & f_{86} & f_{87} & 0 & f_{89} & f_{810} & f_{811} & f_{812} & f_{813} & f_{814} & f_{815} & f_{816} & f_{817} & f_{818} & f_{819} & f_{820}\\
f_{91} & f_{92} & f_{93} & f_{94} & f_{95} & f_{96} & f_{97} & f_{98} & 0 & f_{910} & f_{911} & f_{912} & f_{913} & f_{914} & f_{915} & f_{916} & f_{917} & f_{918} & f_{919} & f_{920}\\
f_{101} & f_{102} & f_{103} & f_{104} & f_{105} & f_{106} & f_{107} & f_{108} & f_{109} & 0 & f_{1010} & f_{1011} & f_{1013} & f_{1014} & f_{1015} & f_{1016} & f_{1017} & f_{1018} & f_{1019} & f_{1020}\\
f_{111} & f_{112} & f_{113} & f_{114} & f_{115} & f_{116} & f_{117} & f_{118} & f_{119} & f_{1110} & 0 & f_{1112} & f_{1113} & f_{1114} & f_{1115} & f_{1116} & f_{1117} & f_{1118} & f_{1119} & f_{1120}\\
f_{121} & f_{122} & f_{123} & f_{124} & f_{125} & f_{126} & f_{127} & f_{128} & f_{129} & f_{1210} & f_{1211} & 0 & f_{1213} & f_{1214} & f_{1215} & f_{1216} & f_{1217} & f_{1218} & f_{1219} & f_{1220}\\
f_{131} & f_{132} & f_{133} & f_{134} & f_{135} & f_{136} & f_{137} & f_{138} & f_{139} & f_{1310} & f_{1311} & f_{1312} & 0 & f_{1314} & f_{1315} & f_{1316} & f_{1317} & f_{1318} & f_{1319} & f_{1320}\\
f_{141} & f_{142} & f_{143} & f_{144} & f_{145} & f_{146} & f_{147} & f_{148} & f_{149} & f_{1410} & f_{1411} & f_{1412} & f_{1413} & 0 & f_{1415} & f_{1416} & f_{1417} & f_{1418} & f_{1419} & f_{1420}\\
f_{151} & f_{152} & f_{153} & f_{154} & f_{155} & f_{156} & f_{157} & f_{158} & f_{159} & f_{1510} & f_{1511} & f_{1512} & f_{1513} & f_{1514} & 0 & f_{1516} & f_{1517} & f_{1518} & f_{1519} & f_{1520}\\
f_{161} & f_{162} & f_{163} & f_{164} & f_{165} & f_{166} & f_{167} & f_{168} & f_{169} & f_{1610} & f_{1611} & f_{1612} & f_{1613} & f_{1614} & f_{1615} & 0 & f_{1617} & f_{1618} & f_{1619} & f_{1620}\\
f_{171} & f_{172} & f_{173} & f_{174} & f_{175} & f_{176} & f_{177} & f_{178} & f_{179} & f_{1710} & f_{1711} & f_{1712} & f_{1713} & f_{1714} & f_{1715} & f_{1716} & 0 & f_{1718} & f_{1719} & f_{1720}\\
f_{181} & f_{182} & f_{183} & f_{184} & f_{185} & f_{186} & f_{187} & f_{188} & f_{189} & f_{1810} & f_{1811} & f_{1812} & f_{1813} & f_{1814} & f_{1815} & f_{1816} & f_{1817} & 0 & f_{1819} & f_{1820}\\
f_{191} & f_{192} & f_{193} & f_{194} & f_{195} & f_{196} & f_{197} & f_{198} & f_{199} & f_{1910} & f_{1911} & f_{1912} & f_{1913} & f_{1914} & f_{1915} & f_{1916} & f_{1917} & f_{1918} & 0 & f_{1920}\\
f_{201} & f_{202} & f_{203} & f_{204} & f_{205} & f_{206} & f_{207} & f_{208} & f_{209} & f_{2010} & f_{2011} & f_{2012} & f_{2013} & f_{2014} & f_{2015} & f_{2016} & f_{2017} & f_{2018} & f_{2019} & 0
\end{bmatrix}$$

$$=\begin{bmatrix}
0&1&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&1&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&1&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&1&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&1&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&1&0&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&1&0&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&1&0&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&1&0&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&1&0&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&10&0&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&1&0&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&1&0&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&1&0&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&1&0&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&1&0&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&8&0&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&1&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&1\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0
\end{bmatrix}$$

Task Allocation Matrix:

$$A = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \\ a_{31} & a_{32} \\ a_{41} & a_{42} \\ a_{51} & a_{52} \\ a_{61} & a_{62} \\ a_{71} & a_{72} \\ a_{81} & a_{82} \\ a_{91} & a_{92} \\ a_{101} & a_{102} \\ a_{111} & a_{112} \\ a_{121} & a_{122} \\ a_{131} & a_{132} \\ a_{141} & a_{142} \\ a_{151} & a_{152} \\ a_{161} & a_{162} \\ a_{171} & a_{172} \\ a_{181} & a_{182} \\ a_{191} & a_{192} \\ a_{201} & a_{202} \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ 1 & 0 \\ 1 & 0 \\ 0 & 1 \\ 1 & 0 \\ 1 & 0 \\ 0 & 1 \\ 1 & 0 \\ 1 & 0 \\ 0 & 1 \\ 0 & 1 \\ 1 & 0 \\ 1 & 0 \\ 0 & 1 \\ 1 & 0 \\ 1 & 0 \\ 0 & 1 \\ 0 & 1 \\ 1 & 0 \\ 1 & 0 \end{bmatrix}$$

Using the Matlab HIQ function with the above data we get: **HIQ = 42.839;** hence **UIQ = 100 – 42.839 = 57.161**

OS5 "Go to Webpage" Task

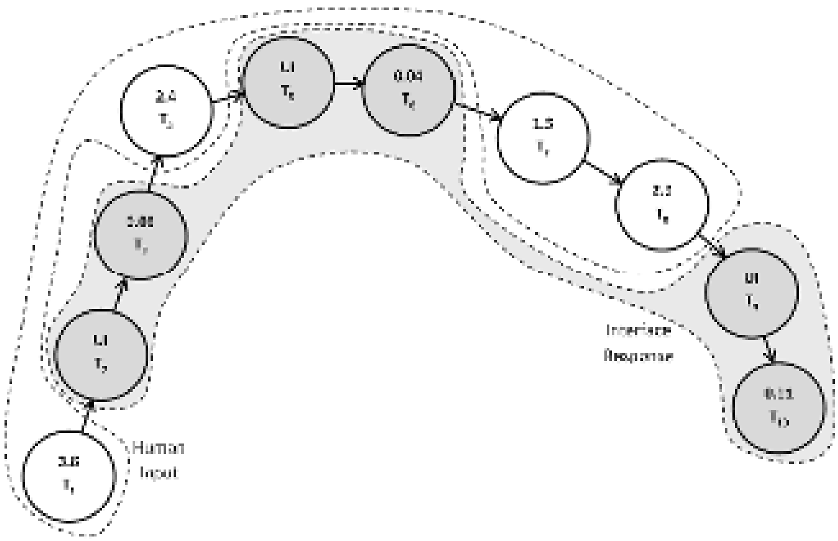

Figure 83. OS5 "go to webpage" task graph.

Table 43. OS5 “go to webpage” subtask complexities.

Task	Go To Webpage	Average
1	Locate Browser	3.8
2	Response from Phone	UI
3	Response from Phone	0.09
4	Locate Address Area	2.4
5	Response from Phone	UI
6	Response from Phone	0.04
7	Enter Address	8.3
8	Click on Go	2.9
9	Response from Phone	UI
10	Response from Phone	0.11

Task Set:

$T = \{T_1, T_2, T_3, T_4, T_5, T_6, T_7, T_8, T_9, T_{10}\}$

Difficulty Set:

$\tau = \{\tau_1, \tau_2, \tau_3, \tau_4, \tau_5, \tau_6, \tau_7, \tau_8, \tau_9, \tau_{10}\}$

$\tau = \{3.8, \tau_2, 0.09, 2.4, \tau_5, 0.04, 8.3, 2.9, \tau_9, 0.11\}$

Data Transfer Matrix:

$$F = \begin{bmatrix} 0 & f_{12} & f_{13} & f_{14} & f_{15} & f_{16} & f_{17} & f_{18} & f_{19} & f_{110} \\ f_{21} & 0 & f_{23} & f_{24} & f_{25} & f_{26} & f_{27} & f_{28} & f_{29} & f_{210} \\ f_{31} & f_{32} & 0 & f_{34} & f_{35} & f_{36} & f_{37} & f_{38} & f_{39} & f_{310} \\ f_{41} & f_{42} & f_{43} & 0 & f_{45} & f_{46} & f_{47} & f_{48} & f_{49} & f_{410} \\ f_{51} & f_{52} & f_{53} & f_{54} & 0 & f_{56} & f_{57} & f_{58} & f_{59} & f_{510} \\ f_{61} & f_{62} & f_{63} & f_{64} & f_{65} & 0 & f_{67} & f_{68} & f_{69} & f_{610} \\ f_{71} & f_{72} & f_{73} & f_{74} & f_{75} & f_{76} & 0 & f_{78} & f_{79} & f_{710} \\ f_{81} & f_{82} & f_{83} & f_{84} & f_{85} & f_{86} & f_{87} & 0 & f_{89} & f_{810} \\ f_{91} & f_{92} & f_{93} & f_{94} & f_{95} & f_{96} & f_{97} & f_{98} & 0 & f_{910} \\ f_{101} & f_{102} & f_{103} & f_{104} & f_{105} & f_{106} & f_{107} & f_{108} & f_{109} & 0 \end{bmatrix}$$

$$= \begin{bmatrix} 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 11 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

Task Allocation Matrix:

$$A = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \\ a_{31} & a_{32} \\ a_{41} & a_{42} \\ a_{51} & a_{52} \\ a_{61} & a_{62} \\ a_{71} & a_{72} \\ a_{81} & a_{82} \\ a_{91} & a_{92} \\ a_{101} & a_{102} \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ 1 & 0 \\ 1 & 0 \\ 0 & 1 \\ 1 & 0 \\ 1 & 0 \\ 0 & 1 \\ 0 & 1 \\ 1 & 0 \\ 1 & 0 \end{bmatrix}$$

Using the Matlab HIQ function with the above data we get: **HIQ = 20.805;** hence **UIQ = 50 – 20.805 = 29.195**

Vita

Ahmed Tawfik El Zarka was born in Giza, Egypt. He was educated in a local public school and moved to the United Arab Emirates at the age of 7. After graduating from Arab Unity School in 2006, he was accepted at the American University of Sharjah, U.A.E., from which he graduated in 2010. His degree was a Bachelor of Science in Computer Engineering.

Mr. El Zarka then began the Master's program in Computer Engineering at the American University of Sharjah and was accepted as a graduate teaching assistant and awarded a full scholarship in his program. He was awarded the Master of Science degree in Computer Engineering in 2013.