Content

[1. Introduction 2](#_Toc429332465)

[2. Problem description 2](#_Toc429332466)

[2.1. Background 2](#_Toc429332467)

[2.2. Data explanation 5](#_Toc429332468)

[2.3. Problem analysis 7](#_Toc429332469)

[2.4. Problem in mathematical meaning 8](#_Toc429332470)

[3. Literature review 9](#_Toc429332471)

[3.1. Single machine makespan with sequence dependent setup time 9](#_Toc429332472)

[3.2. Beam search application 11](#_Toc429332473)

[4. Methodology and Modelling 11](#_Toc429332474)

[4.1. Branch-and-bound 11](#_Toc429332475)

[4.2. The Beam Search Heuristic 12](#_Toc429332476)

[References 14](#_Toc429332477)

# 1. Introduction

In this paper, a specific scheduling problem which is regarded as a single machine problem in a service industry with uncertain sequence setup time to minimizing Makespan is considered. In field of scheduling, the problem of allocating the resources within the given time periods as well as obtaining the optimization of projects’ objectives should implement the useful algorithms to make schedule reasonably and efficiently. This paper presents a dog walking problem and aims to find out a feasible solution to achieve the target of scheduling a reasonable timetable for dog walker to make the duration of the whole dog walking activity, otherwise, the Makespan minimum.

Uncertain sequence setup time is a significant factor that gains increasing and considerable attention in scheduling research. Its unique particularity and practical significance decides the widely use of which in actual industries. However, there are no adequate and relative researches focuses on service industries. Different from those manufacture industries, scheduling in services is mostly influenced by human’s subjectivity. Customized operation system decides numerous uncertainties that are problematic to qualify. Therefore the difficulty is added while aiming at a specific problem.

(An outline of the approach/methodology you have adopted)

The following paper is divided into several chapters: Chapter 2 is the detailed description of the problem. In which the company’s background will be introduced as well as the features that involved in the problem will be presented. Based on which the problem analysis is following and the definition of the problem will be proposed here. To deeply analysis the problem will be described in a mathematical style which is helpful for latter research. In Chapter 3 the literature review will be displayed and drawing the support of which the recent researches focus on scheduling aspects such as single machine, makespan, sequence dependent setup time as well as the methodology that will be used in this problem. A clear identification will be held and the content will deepen the understanding of issues. Chapter 4 shows the methodologies that applied in this problem

# 2. Problem description

## 2.1. Problem background

Through the investigation from Pet Food Manufacturers’ Association (PFMA) of pets’ quantities in the UK, dogs are the largest number of pets that households keep which taking 24% of the total sample (pfma.org.uk, 2015). The relationship between dogs and their owners should be kept without the daily contact and accompany, one of the most efficient way to keep dogs’ healthy body and mind is dog-walking (McCormack et al., 2011). However, considering the various reasons that households have no enough time to share with their pets and the potential accident caused by dogs without looking after by owners, the need that taking care of dogs while their owners are busy gives birth to a new occupation, dog walkers, for whom the job is to accept the order from households and ensure specific time periods to bring their dogs out for walking. Dogs\_N\_Joy is such a business that produces households the service of one to one dog walking.

This company is totally ran by its legal representative and now is offering services involves dog walking, dog/puppy feeding visits and cat visits covering a small-scale market. During the developing process of which dog walking takes the significant role in its services but now is gradually becoming the burden due to the conflict between huge workload and limited labour. The general process of an order’s acceptation and services could be described as below:

1. *Accepting order with customer’s requirement and dogs’ information;*
2. *Scheduling all orders;*
3. *On scheduled date and time arriving at customer’s house to collect the dog(s);*
4. *Walking the dog(s) on specific walk location for the pre-determined period;*
5. *Returning the dogs to owners’ house;*
6. *Going to the next customer’s house to pick the dog(s).*

It seems that the whole job is simple but while detailing to the specific situation the uncertainties could occur and make the original event more complexed. The main performances of uncertainties are listed below:

***The uncertain date***: Date order could be vary from different weekdays to holidays, especially the holidays which are not easy to be ensured and only can be remarked until customer has made the decision, these unexpected variables could not be easily taken consider into the daily scheduling;

***The preparation time:*** Before the beginning of the official work, dog walker needs to spend some times on traffic or chat and learn extra information from the households (Sometime households might have some interim decisions), which will also influent the transfer of the work. In addition, customers usually require the flexibility of the collecting time. Which leads to postpone of the original collecting time, exactly it will affect the subsequent work;

***Dogs’ conditions***: Especially the physical conditions of dogs, households might not willing to let dogs out while their pets feel uncomfortable, which resulting in a situation that the original arrangement should be cancelled and causing the indirect economic losses due to it might take place of other possible order when scheduling;

***Dogs’ characteristics:*** This factor decides whether a dog could be scheduled on a specific walk location. As for those agile dogs, it is not feasible to walk them on a crowded place as to prevent the situation of loss or wounding people. In other situations, some dogs should not be walked in an environment that full with cyclists or horses, which might easily make dogs frighten. Therefore finding a suitable place that can mostly satisfy dogs’ characteristics is also the key point of this problem;

***Dogs’ compatibility***: It is important in this business because in order to obtain the utility maximization, sometimes the business should arrange two or three dogs to walk together in the same period. However, it is not ideal that all kinds of dogs could be put together and enjoy a peace walking, there exists some dogs cannot stand to walk with others and therefore some aggressive behaviours might happen within dogs during the walking time. Unfortunately, this factor is the most difficult point to consider because only after the experimental walking the walker can recognize whether those dogs could safely walk together;

***Routing***: It has been referred that the business service scale covers a specific area. To finish one day’s schedule, the dog walker might needs to go through all nodes around this area by walking or driving, combining with the repeated routines to return the dogs back and the unexpected situations happen on the road, for example, traffic jam or road maintenance, which would take more time compared with the scheduled plan;

***Dog Walker’s situation:*** Considering that the dog walker walks all dogs by person, it is hard to guarantee that walker’s situation will always match the intensity of work. It is apparently that walking a large dog is much difficult than a small one, sometimes it also needs walker to pay extra energy to look after those energetic dogs. Furthermore, the scheduled work may affect the walker’s daily routine so much as walker cannot take lunch or enough rest on time. Thus, walker is easily to get into tired after daily walking job not to mention that how great on walker’s mental and physical burden after a whole week’s working, which would also deeply prevent the formal schedule.

In general, there should be an information flow exists in service industry which is diverse among different businesses. For Dogs\_N\_Joy it could be explained as below:

Feedback

Accept/reject (conditions)

Customer

Scheduling

Make reservations/orders

Database

Data collecting

Data support

Order Execution

Service

Figure 2.1.1 Information flow diagram in Dogs\_N\_Joy

From Figure 2.1.1 it is clear that the key point involved in this flow is the transfer of data. To service industry, the judgement standard is not simply decided by hardware conditions compared with those manufacturing system but mostly rely on the data support, which links deeply with resources availability as well as the potential customers market. As for Dogs\_N\_Joy, ensuring the walking environment and dogs’ compatibility could be regarded as the essential points for services quality. As it is mentioned by Pinedo (2008a) that scheduling should be “coordinated with other decision making functions” in services environment. In other words, the data contain the dogs’ compatibility and the situation of walk locations plus other restrictions should be the constraints to help establishing the related heuristics later.

## 2.2. Analysis of data

Data involved in the problem derive from the customers’ requirement and dogs’ information as well as dog walker’s daily experience. First of all, a completed order from customer is constituted with three categories, which could be sorted as: *Customers’ information*, *Dogs’ information* and *Customers’ requirement.*

In customers’ information the post code of households is noted and with which a detailed marketing distribution is displayed on the map. Given a location on the map usually stands several useful information, for instance, it can help researcher to gain coordinates, the usage of which will be referred later. On the aspect of dogs’ information, it mainly includes dogs’ name, dogs’ breed as well as their size. In customers’ requirement, the time to start the job is noted which involves the ensured day and the specific time, the duration of each job is also emphasized. Furthermore, the flexibility of the time to collect the dog is also recorded, which represents the range of period that customers might ready to let their pets be collected. For example, if the initial ensured time is 12 am and the flexibility is one hour, therefore the time for collecting could be randomly distributed between 12am to 1pm. Apart from these orders involve clear information; others which lack enough messages are categorized to non-regular category. Customers in this set do not give the specific time but mention the permitted time should be holiday or working period. While considering this kind of jobs it is better to distinguish them from those regular orders.

The second part is dogs’ compatibility. It is totally decided by dog walker’s experience. Through the experimental walking and accompany with different dogs, dog walker can judges the dogs’ characteristics and temperament. Therefore the status of compatibility is divided as below:

* *Not compatible*: The dogs cannot be walked together;
* *Unknown*: This would be set for a new dog, which should be walked firstly by dog walker then the detailed experience could be gained. Before obtaining the new information this set of dogs are treated as the kind that cannot be put together with other dogs;
* *Probably compatible*: Through dog walker’s judgement, dogs in this set could be put together;
* *Compatible*: Dogs in this set are already walked before and are proved that they can walk together exactly.

From the view of data, dogs’ compatibility situations are considered and sorted as below: The former four judged standards are transferred into numbers where *Not compatible, Unknown, Probably compatible, Compatible* is corresponds with -1, 0, 1, and 2 respectively. The detailed structure of compatibility is designed into the Table 2.2.1 as displayed as an example:

Table 2.2.1 Dogs’ compatibility situation

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Cust No. |  | 0 | 1 | 2 | …. | m-1 | m |
|  | Dog Name | Dog a | Dog b | Dog c | …. | Dog (m-1) | Dog m |
| 0 | Dog a |  | 2 | 1 | …. | 0 | -1 |
| 1 | Dog b |  |  | -1 | …. | 1 | 1 |
| 2 | Dog c |  |  |  | …. | 0 | -1 |
| …. | …. | …. | | | | | |
| m-1 | Dog (m-1) |  |  |  | …. |  | 1 |
| m | Dog m |  |  |  | …. |  |  |

Due to the difficulty basis on irregular characteristic, for example, from Table 2.2.1 assuming dog share the same period to walk in the same day, and are experimented to be compatible with the number 2, the situation is the same between and, however, and are not compatible. The problem is occur that between the combination of and, which one should be chosen finally and how remained one can affect the following scheduling.

The final part is information about walk location. Through dog walker’s experiences, the summary of dogs’ characteristics is finished and clearly presents that whether the dog is feasible to walk in an environment that includes items in cyclists, joggers, horses, traffics and so on. Corresponding with which there are several walk locations that have been inspected and found that the specific items exist in them. This information is significant because it is used to judge the best place to walk the dog and prevent those unexpected accidences. In other words, the walk location provides another type of restriction on the time to go to the walk location. Combining the above information, we can conclude the detailed processing procedure as below:

Job 1

Job 2

Figure 2.2.1 Processing procedure of dog walking

From Figure 2.2.1, the first job of every weekday is starts from the dog walker’s home at time and takes time period to arrive at the first customer’s house. After collecting the dog then turning to the next customer’s house to collect another dog and consuming time period, the same process on period to collect the final dog (Assuming that in Job 1 there are three dogs should be walked together). Next the dog walker need to take the time period to arrive at the first walk location through time period, the white block stands the walk duration. After finishing the walking task, the dogs need to be returned to their households respectively. Thus, and represent the time that returning the third dog, second dog and first dog. Here the rule is following the minimum cost on time. Therefore Job 1 is already finished at time, and Job 2 begins, following the similar process of Job 1, in Job 2 there is only one dog should be walked and also, is the time period to arrive the second walk location, which maybe a new location or the initial one.

## 2.3. Definition of Problem

According to the work environment and scheduled objectives, scheduling problem is divided into several aspects, single machine problem is the main issue of them and is as the same situation as in dogs walking problem. In order to facilitate the description, dogs walking problem is going to be treated as single machine problem in the following chapters. Researching of single machine problem not only can produces insights to a specific single machine environment but also positive to establishing the based heuristics for those more complicated machine environment (Pinedo, 2008b). A reasonable scheduling on single machine of those specific projects could efficiently affect the performance of services provided and directly influent the evaluation from customers and business reputation.

Due to the importance of single machine model in scheduling problems, there are numerous researchers studied on it start from different given constraints. In Allahverdi’s research of comprehensive survey on scheduling, basis on the single machine environment, the problem could be classified by the number of jobs at each stage, the requirements of processed job, setup time/cost and the optimizable performance measure (2015a). Combining with the problem considered in this paper, the setup time/costs is the key factor to be taken into the consideration. In Allahverdi’s opinion, there are two styles of setup time/costs, one is sequence-dependent and the other is sequence-independent (2015b). The difference between them is focus on whether the former job can influence the setup for its next job by the machine (Driessel and Mönch, 2011). In dogs walking problem, while dog walker has finish one job, the setup time to consume before starting the next job is surely affected by the former time consuming on the road between walk location and household’s address, also including extra potential influenced factors, which in other words, could be regarded as unpredictable at the beginning. Thus, adding the objective, the dog walking problem should be defined as the single machine problem to minimize Makespan with uncertain sequence-dependent setup time problem.

## 2.4. Problem in mathematical meaning

In the following part of this paper, all the scheduling problems will be described as a triplet proposed by Graham et al. (1979), within which stands the scheduling environment, stands restrictions and jobs characteristics, stands the objective to be minimized in the problem.

After analysing the former factors, the problem could be described as follows: There are a set of orders of dog walking (One order corresponds with walking one dog). Dog walker can handle at most three orders at a period, which could be presented as an order batch, here stands the number of orders in an order batch. Therefore, assuming dog walker executes one job which involves an order batch and there are jobs to be scheduled on every required weekday (Monday to Friday). Hence we establish a function of scheduled job, which mean the job is put on the position of weekday and has dog(s) to be walked. For example, represents the job is put on Monday and will be executed as the third job of that day which contains 2 dogs to be walked. The scheduling is regarded as non-pre-emption due to consensus obtained between dog walker and clients. Given that each job has a normal processing time, in dogs walking problem is the duration of walking, and represents the actual processing time that adding the setup time to and the job is started at time in a weekday’s sequence. Our goal is to figure five sequences and make each of them obtains the minimized, while represents the time to complete the job. Therefore, we could obtain a problem.

# 3. Literature review

## 3.1. Single machine makespan with sequence dependent setup time

Numerous researches have been done on single machine makespan with sequence dependent setup time problem, dating back to the last century, Irani, Gunasena and Davachi (1988) produced a set of technology-based heuristic to solve the sequence setup-dependent problem on single machine and ideally used an approach of “nearest neighbor” to solve the Traveling Salesman Problem (TSP) and emphasized that a dominant set of schedules can be considered with other time studies.

As the time running, the same problem is given the more complexed realistic meaning. Ángel-Bello et al. (2011a) suggested a Mixed Integer (MIP) model and successfully solved the large sample scheduled problem with a linear relaxation model and a well-organized heuristic. Basis on it, Ángel-Bello et al. (2011b) assumed that the machine is availability constraints and proposed a metaheuristic focus on Greedy Randomized Adaptive Search Procedures (GRASP). On the aspect of extra condition on setup time applied in the actual problem, Rojas-Santiago et al. (2014) proposed a combination method of Lagrangean Relaxation (LR) and 2-opt to minimize the makespan and effectively solve the specific number of jobs’ scheduling. For more detailed research on job’s processing time, Bahalke et al. (2010) established the mathematical model and applied Tabu Search (TS) algorithm and Genetic Algorithm to deal with the specific deteriorating jobs to address the explicit change which occurs among different jobs while an increasing function is presented to imply a job’s original time. With the application of TS, Pacheco et al. (2013) solved the problem which involves two NR-hard problems and could also handle the large size of instances sample. With the continuously research on the same problem in which the setup times are time-dependent except sequence-dependent, Stecco et al. (2008) proposed the branch-and-cut algorithm and later they found TS could lead to less computed time compared with the former one (2009). To ideally respond to changeable marketing situation, Ying and BinMokhtar (2011) proposed a simple heuristic algorithm to minimize the makespan as well as the total sequence time. Yang and Yang (2010), Bai et al. (2012), Wang et al. (2012) put their mind on the influences of learning and deterioration to single machine problems and in their opinion polynomial solutions can efficiently solve the related problems and Bai et al. (2012) also proved that under the specific cases the problem of makespan minimization is still polynomially solvable. Yang and Chand (2008) creatively proposed branch-and-bound heuristic to probe the effects brought by learning and forgetting of the sequence setup time within the single machine problems and basis on which Pan et al. (2014) improved the search algorithm and figured out the way to reduce the time consuming during the process procedure.

Similar researches has been done by Wang and Wang (2012), they focused on nonlinear shortening processing time and proposed the problem, both and are large than 0 and the former is a given parameter with the latter one stands a rate of change. According their assumption and calculation, they proved that in a makespan minimization problem, the optimal sequence is V-shaped with regard to the normal processing times of the jobs. Based on which their algorithm is designed, in which the position of partial sequences is interchanged by calculating the smallest makespan through using the former formulation. Wei et al. (2012) used another condition to consider the objective involving four targets contains makespan at the same time. They put the time and resources together and proposed times’ model, here is the common worsening rate, represents a non-renewable resource allocated to a specific job. Through computation and comparison they obtained the final results and proved that the problem is still polynomially solvable under that model. Above researches both using the mathematical hypothesis to prove the existence of the minimum makespan and gaining the wanted algorithm through the theory.

Aforementioned content includes several specific approaches that could be adapted into the single machine scheduling problem and most of them are focus on the parameter of time. Aiming at each different problem the different approach can obtain the ideal result on the aspect of reducing the scheduling time or finding out the optimal solution. Only to match the features of different approaches to the specific conditions exist in problem that the procedure to optimize the whole scheduling plan can be efficiently simplified. For example, TS is viewed as an ideal algorithm for those problems that exist the consideration of choosing an optimal schedule from the original options, which could also applied in the TSP to satisfy an adequacy criterion, it can generates randomly from an initial solution to find whether the new better solution could be figured and avoiding cycles in the map. Finally it gains a set of solutions that are added to the tabu-list which emphasize that all solutions are neighbored. However, the apparent drawback is that if the entries’ number is too small, the cycle might occur (Pinedo, 2008c).

Recurring to dogs walking problem, it is worth noticing again that the key factors in this problem is the time. From the initial status of deciding the general sequence of dogs order, scheduler needs to consider about the time span of one order. Adding the requirement of walking a dog set (At most three) wherein dogs are compatible with each other or only one dog in a set due to it should be walked alone, it is clear to figure that to pursue the minimum makespan the problem possesses the feature to chase a combinatorial optimal target. Considering that this kind of problem is NP-hard, the constructive thinking should be implemented with dogs walking problem.

## 3.2. The application of constructive heuristics

The researches focus on finding the optimal or near-optimal solutions for specific problems via constructive heuristics cover wide areas and involve various different types of scheduling aspect. Danilovic and Ilic (2015) adopt insertion-based heuristic into a generalized constructive algorithm (GCA) and started from a purely theoretical view to pursue the possibility of selecting more widely diversity of heuristics through argument values. They successfully extended the thinking of previous algorithm for a permutation flowshop problem (PFSP). In their study, constructive heuristic’s formalization was presented as a quadruple (*I, F, C, g*), which clarified the basic routing of explaining a combinatorial optimization problem. Vanchipura et al. (2014) implemented an improved constructive heuristics to solve a flow shop scheduling with sequence dependent setup time problem, also targeted to the minimum makespan. They applied two existing constructive algorithms to generate an original solution, one is NEHRB (Ríos-Mercado and Bard, 1998), and the other is FJSRA (Vanchipura and Sridharan, 2012). NEHRB tries to use the sum of processing times of different machines to identify the order of partial sequence while FJSRA applies the thinking of substitution, within which the setup time between two jobs is treated as a virtual job. Both of them are trying to figure out the partial sequence with minimum makespan then to decide the order. Here it could be obtained that constructive heuristics can efficiently adapt elastic requirements in specific problem. The thinking of swap and move within the scheduling models can efficiently the detailed points in problems.

The constructive heuristics also implemented within a vehicle routing problem (VRP) by Afshar-Nadjafi and Afshar-Nadjafi (2014). In their research they considered the problem with time-dependent multi-depot and objected to minimize the total heterogeneous cost. They also established a constructive heuristics basis on a mixed integer programming model and finally obtained their initial assumption by evaluating a test problem with a large size of samples. Particularly, in their designed chapter of the constructive heuristics, they applied time windows to help them ensuring the priority of customers, which is also worth learning in dogs walking problem.

Other specific constructive heuristic is proposed by Nagano et al. (2014). In their paper they discussed a scheduling problem with sequence dependent setup time in a no-wait flowshop and objected to minimize the total flow time. Aiming at such a NP-hard problem they produced a new constructive heuristic called QUARTS. With the references of the previous researches on other two basic constructive heuristics BIH and BAH (Bianco, Dell’Olmo & Giordani, 1999) as well as TRIPS (Brown, McGarvey and Ventura, 2004), they designed QUARTS to break the total problem into several quarters to gain the minimum flow time. From here the thinking of discussing the shortest processing time in a phased view is also useful in solving the part of dogs walking problems. Obviously, while considering the partial schedule of morning and afternoon’s sequences, that thinking should be fit on it.

# 4. Methodology and Modelling

## 4.1.

## 4.2.

# 5. Methodology and Modelling

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