

Chapter 2

Literature Review and Research Objectives

2.1 Introduction

The concept of robotic flexible assembly cell (RFAC) has the potential to introduce significant improvements in system performance, as highlighted in Chap. 1. To achieve these improvements, the problems of RFAC at scheduling level need to be critically addressed. To date, researchers have paid little attention to handling the scheduling problems relevant to RFAC.

The main reason for limited research on the scheduling of RFAC is because such a system requires a sophisticated *scheduling approach* not only to guarantee higher system utilisation but also to prevent collisions between robots in the shared area. Based on this restriction, the literature review in this chapter is conducted from two viewpoints: Firstly, a review of the advanced scheduling approaches that have been successfully applied to the scheduling of manufacturing systems. Secondly, a review of the existing solution approaches that have been devoted to solving scheduling of RFAC. The overall purposes of this chapter are listed as follows:

- To summarize the scheduling problems in manufacturing systems and the advanced scheduling approaches that deal with these problems;
- To review the existing approaches to scheduling problems in RFAC;
- To identify the research limitations in the existing approaches to scheduling RFAC;
- To highlight the research objectives of this thesis; and
- To introduce the research plan to achieve the research objectives.

2.2 Scheduling Problems in Manufacturing Systems

Scheduling is a decision-making process that plays a vital role in most manufacturing industries. The scheduling function optimizes the *limited-resources* allocation to the processing of *jobs* (Pinedo 2005). Resources include machines, robots, tools, material handling equipment and materials to be processed. A job consists of a number of operations or tasks to be done in the manufacturing systems. The scheduling problems in manufacturing systems have several different aspects.

The next sub-section summarizes the three main aspects: types of scheduling problems, characteristics of scheduling problems and the solution approaches that can be used for addressing the scheduling problems in manufacturing systems.

2.2.1 Types of Scheduling Problems

Scheduling problems are theoretically categorized by a number of types. French (1982), Blazewicz et al. (1994) and Pinedo (2012) classified scheduling problems according to several criteria such as production volume, nature of production, production capacity and manufacturing systems. Each type of scheduling problem has different levels. The common types of scheduling problems with their levels are summarized in Table 2.1. In practice, the number of scheduling levels can be combined to characterize a single manufacturing environment.

Many researchers have studied the scheduling problems when the system status is either static or dynamic. These two scheduling levels are defined as follows:

- *Static scheduling* is a process that produces a fixed plan based on a set of activities when all information about the jobs is known, prior to the start of the scheduling process. The outcome of this type of scheduling cannot be changed or adapted during operating time (Jain and Elmaraghy 1997).

Table 2.1 Different types of scheduling problems (Arisha 2003)

Classification based on	Scheduling level
Production volume	High volume scheduling Intermediate volume scheduling Low volume scheduling
Nature of production	Activity scheduling Batch scheduling Network scheduling
Production capacity	Infinite capacity scheduling Finite capacity scheduling
Manufacturing systems	Flow shop scheduling Job-shop scheduling Flexible manufacturing system scheduling
State of scheduling	Static scheduling Dynamic scheduling

- *Dynamic scheduling* represents a process that creates a variable plan. Hence, dynamic scheduling is flexible, accommodating additional unexpected events such as order cancellation, arrival of urgent orders, due date changing and unavailability of tools. A dynamic scheduling plan is therefore able to respond to the market environment (Ouelhadj and Petrovic 2009a, b; Chryssolouris and Subramanian 2001).

2.2.2 Characteristics of Scheduling Problems

The characteristics of scheduling problems in manufacturing systems are specified by a set of elements. The critical elements are: decision variables, constraints, and objective functions. These elements are briefly described in the following paragraphs.

Decision variables: The decision variables consider the important elements in scheduling problems. The scheduling managers employ the decision variables to match activities and resources to finish jobs and simultaneously to optimise the system performance. The common types of decision variables (Arisha 2003) are:

- Sequencing;
- Routing;
- Timing/release; and
- Resource and activity reconfiguration.

Constraints: Most real-life scheduling problems are nondeterministic polynomial-time hard (NP-hard) and tend to have a number of constraints to generate a reliable solution. French (1982), Pinedo and Chao (1999) and Brucker (2007) listed many of the constraints that are faced in the scheduling process. The common constraints are:

- Precedence and routing constraints;
- Tooling, resources, material handling constraints;
- Industry type and automation constraints; and
- Demand pattern and capacity constraints.

Objective functions: The objective of any manufacturing company is to maximize the utilization of the resources, minimize the completion time and meet the due date of customer orders. These objectives are normally in conflict with each other and no single solution can satisfy all the objectives. Hence, the target of these companies is to strike a profitable balance among these conflicting objectives (Hopp 2001). In the scheduling area, several objective functions are used to evaluate the system's performance under different scheduling strategies. (Ramasesh 1990) categorized the objective functions into four types:

- Time-based objectives;
- Work-in-process objectives;

- Due-date-based objectives; and
- Cost-based objectives.

2.2.3 *Solution Approaches*

Extensive research has been done on aspects related to scheduling of manufacturing systems. Due to the complexity of scheduling problems, several solution approaches have been proposed. These approaches can be grouped into two major types: traditional and advanced solution approaches, as shown in Fig. 2.1.

Traditional approaches can be classified into two categories: analytical and heuristic approaches. These approaches can often result in near optimal solutions. However, they are applicable to only small-sized scheduling problems (Pongcharoen et al. 2002; Oduguwa et al. 2005). Traditional approaches are also inflexible, inefficient and slow to satisfy real-world scheduling problems (Shen 2002).

Advanced approaches can also be classified under two main categories, i.e. simulation approaches and artificial intelligence approaches. These approaches have also been utilised for scheduling problems in manufacturing systems. Ouelhadj and Petrovic (2009a, b) and Rajabinasab and Mansour (2011) showed that the recent studies on scheduling problems are based on simulation approaches and artificial intelligence approaches due to two reasons. First, the solutions obtained are more promising than traditional approaches. Second, advanced approaches reduce the time needed to find the solutions compared to traditional approaches. Hence, only the studies that used advanced approaches in scheduling of manufacturing systems will be reviewed here.

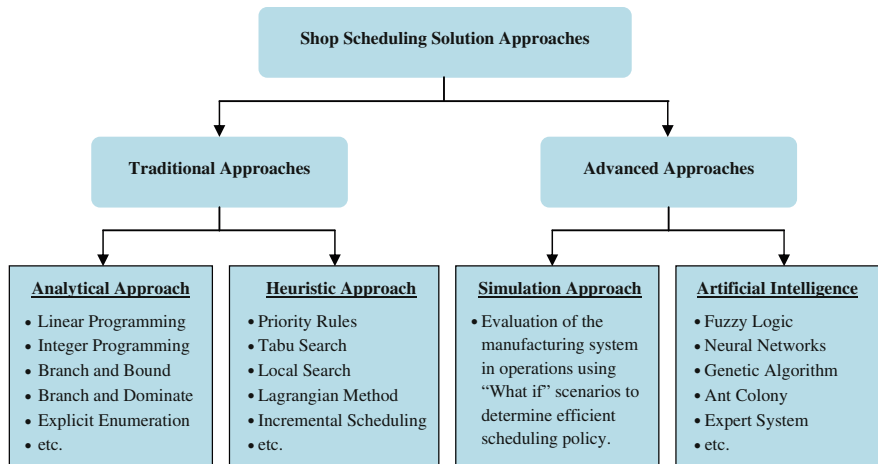


Fig. 2.1 Shop scheduling solution approaches

2.3 Review of Literature on Advanced Scheduling Approaches

There are a number of studies in the literature which look at the problems of scheduling using advanced approaches. These studies are divided into two groups as described in the next sub-section.

2.3.1 *Simulation Approaches*

The complexity and dynamic behavior of manufacturing systems make simulation one of the most powerful approaches for addressing scheduling problems. In the last decade, simulation-based approaches have been extensively used for scheduling problems. In these approaches, different scheduling rules are compared via simulation experiments to find the optimal solutions. For example, Mohanasundaram et al. (2002) developed efficient rules for scheduling in a dynamic assembly job shop. They compared their proposed rules with traditional scheduling rules via extensive simulation. The authors conducted the simulation experiments using two factors, namely dynamic arrival of jobs and due date changing. The simulation results indicated that the developed rules performed very well for different performance measures.

Dominic et al. (2004) combined two scheduling rules for dynamic job shop scheduling. The simulation experiments were performed using dynamic arrival of jobs and due date changing. The simulation results indicated that combined rules provided better performance. The results also showed that no single scheduling rule was effective in optimizing all performance measures.

Caprihan and Wadhwa (2005) used a simulation based approach together with Taguchi experimental design method for studying the performance of semi-automated flexible manufacturing systems under different scheduling factors. They adopted Taguchi method for conducting the experiments as well as for analyzing the simulation results.

Thiagarajan and Rajendran (2005) proposed several scheduling rules for a dynamic assembly job shop. They conducted the simulation experiments using dynamic arrival of jobs and due date changing. The results of the simulation indicated that the proposed rules were effective in optimizing multiple performance measures.

Viond and Sridharan (2008) developed five new setup oriented scheduling rules for a dynamic job shop system, and then compared the proposed rules with several common rules via experimental studies. They set up the experiments using a multi-factor experimental design: arrival of jobs, due date tightness and setup time ratio. The simulation results verified that the proposed setup oriented rules performed better than other common scheduling rules.

Ali and Wadhwa (2010) utilized simulation based approach and Taguchi method to determine the optimal combination of scheduling factors in a flexible manufacturing

system (FMS). They applied Taguchi method to study the various scheduling factors and determine the important factors for improving FMS performance.

Kianfar et al. (2009) proposed new rules for dynamic flow shop scheduling. They considered dynamic arrival of jobs and the ability of acceptance and rejection of new jobs. The simulation experiments were conducted under different conditions of arrival of jobs, due date tightness and number of stages in the flow shop. The simulation results showed that the suggested new rules performed better than existing scheduling rules.

Vinod and Sridharan (2011) proposed a new methodology by investigating the interaction between scheduling rules and due date assignment methods in a dynamic job shop production system. The examined due date assignment methods were dynamic plus processing waiting time (DPPW), random work content (RWK), total work content (TWK) and dynamic total work content (DTWK). The statistical result showed a significant interaction between scheduling rules and due date assignment methods.

Caprihan et al. (2013) studied the effects of different scheduling rules on the performance of dynamic scheduling in a FMS. They considered five factors to construct a simulation experiment. These factors were information delay, routing flexibility, due date tightness, scheduling rules and dispatching rules. They used Taguchi experimental design to minimise the number of experiments as well as to analyses the simulation results. The statistical results proved that the constructed simulation model was able to demonstrate the impact of different scheduling factors on FMS performance.

2.3.2 Artificial Intelligence Approaches

Artificial intelligence approaches, such as genetic algorithms (GA), fuzzy logic (FL), ant colony optimization (ACO) and neural networks (NN) have been utilized for scheduling problems. These researchers used intelligent approaches to propose an appropriate scheduling rule, and then compared the outcome of the proposed rule with other existing scheduling rules. For instance (Tang et al. 2005) developed a rule based on NN for the dynamic scheduling of the flexible flow shop. They considered dynamic job arrivals and due date changing. The simulation results showed that the NN approach was better than all other common scheduling rules.

Vinod and Sridharan (2008) used a FL approach to propose new scheduling rules for a dynamic job shop environment. They built a discrete event simulation model to compare the proposed rules with traditional scheduling rules. The simulation experiments were conducted via due date changing and dynamic arrival of jobs. The simulation results showed that the proposed rules performed very well.

Zhou et al. (2009) proposed a new rule based on ACO for solving dynamic job shop scheduling. They examined the approach with different levels of jobs arrival,

due date changing and processing time distributions. The results showed the ACO performed better than the existing scheduling rules.

Moradi (2010) integrated the flexible job-shop scheduling problems with preventive maintenance activities using GA, to reduce the probability of machine and equipment breakdowns. They employed Taguchi method to calibrate all the factors of scheduling problems and to analyze the results statistically.

Lu and Liu (2011) developed a dynamic scheduling strategy for FMS based on a FL approach. They considered arrival of jobs and due date tightness to set up the simulation experiments. The simulation results showed that the proposed strategy gave superior system performance compared to existing scheduling rules.

Nie et al. (2013) used the concept of GA to propose a rule for dynamic scheduling on the flexible job shop floor. They conducted the simulation experiments using different factors: dynamic arrival of jobs, due date changing and problem flexibility. The results indicated that the proposed rule was more efficient for complex scheduling problems.

2.3.3 *Observations from the Literature Review*

In the previous section, a number of studies devoted to solving dynamic scheduling problems in manufacturing systems were critically reviewed. This review showed the influential events that were considered when dealing with dynamic scheduling problems in manufacturing systems. From this reviewed literature, it can be concluded that:

- The simulation-based approaches and artificial intelligence approaches are both promising approaches for the addressing of dynamic scheduling problems. These approaches demonstrate the feasibility of studying dynamic scheduling problems and finding the optimal or near-optimal solution to maximize the utilization of manufacturing systems.
- Manufacturing systems are mostly operating in dynamic environments. These systems are often subject to factors that may cause deviations from the generated schedules, and the schedule plan may become impractical to implement when it is released to the system (Ouelhadj and Petrovic 2009a, b). Hence, the influential factors must be taken into account when solving the dynamic problems in any given production system (Jain and Elmaraghy 1997; Gholami et al. 2009).
- The Taguchi experimental design is an efficient tool for setting the number of possible experiments and for analyzing the simulation results. Taguchi method has the ability to solve scheduling problems with a greatly reduced number of experiments compared to full factorial experimental methods, in order to find the best combination of the scheduling factors to optimize the objective functions (Ali and Wadhwa 2010; Caprihan et al. 2013).

2.4 Scheduling of RFAC: A Literature Review

Much of the research on the scheduling problems has focused on flexible manufacturing systems. Researchers have paid little attention to handle the scheduling problems in robotic flexible assembly cell (RFAC). As a result, the literature in this area is quite limited.

This literature review can be categorized into three groups (Abd et al. 2010, 2014). The first group applied heuristic methods, while the second group investigated simulation as an approach to scheduling RFAC and the third group implemented expert systems to solve scheduling problems in RFAC.

2.4.1 *Traditional Approaches*

A traditional approach is an uncomplicated method to find reasonably good solutions; however it does not guarantee finding best solution. Some studies have been dedicated to scheduling RFAC, using traditional approaches (analytical and heuristic) as follows.

Nof and Drezner (1993) proposed robot assembly planning and scheduling methodology relating to the allocation of assembly tasks. They formulated a multi-robot operation as a multi-travelling salesmen problem to allow the robots to work without collisions. They considered different configurations of multiple robot workstations. The purpose of this study was to increase the cells' productivity and to reduce the transportation time for robots to pick up parts and assemble them.

Lin et al. (1995) dealt with the problem of printed circuit board (PCB) assembly when two robots are employed concurrently in the same cell. They implemented an algorithm for simultaneous collision avoidance and scheduling operations, also to minimize assembly cycle time and consequently enhance the throughput. The algorithm was divided into three steps: initial insertion sequencing, balancing and re-assignment, and avoiding collision of robots. The computational results demonstrated the performance of the proposed algorithm.

Pelagagge et al. (1995) presented a heuristic approach to solve planning and scheduling problems in robotic assembly cells. They focused on assembly tasks characterization to find acceptable solutions for determining collision avoidance and coordination problems. They divided the assembly area into two categories, outside and inside; the latter represents critical area. The developed approach appeared able to find acceptable solutions that guarantee high utilization of the robots assembly.

Jiang et al. (1998) applied dynamic programming to solve the scheduling problems for a two-robot assembly cell; these robots operated concurrently to assemble one product. The aim of this work was to present algorithms for finding the optimal or semi-optimal movement for each robot in the assembly cell. The main

shortcoming of this study is that, to avoid collision, just one robot has access into the assembly area and the other one stays outside the workplace at all working times.

Marian et al. (2003) proposed a framework for the planning of robotic flexible assembly cell (RFAC). This framework consists of two main modules: off-line and on-line modules. The first module was used to generate an optimal or near-optimal assembly sequence for each product, and was considered as an input module. The second module was used to determine, at every moment, the priority of assembly operations for multi-products in order to use the available resources of the RFAC. The objective was to maximize the throughput of the cell. Although they considered a simple heuristic approach to solve the planning problem of RFAC, they did not address the detailed sequencing of all assembly tasks required to assemble a product, which could result in a better solution.

2.4.2 *Simulation Approaches*

A simulation approach is the imitation of the operations of various real-world facilities. Many of the research studies have been devoted to developing simulation approaches for solving the decision problems in manufacturing systems, including the scheduling problems (Kianfar et al. 2009; Vinod and Sridharan 2011; Caprihan et al. 2013). However few studies, as shown below, have been done to address the scheduling problems in robotic assembly cells.

Gilbert et al. (1990) presented a procedure for the scheduling problems in a multi-robot assembly cell. The objective was to reduce the assembly time required to produce a product. They used two methods: the synchronous method, which enables on-line scheduling, and the asynchronous method, which requires off-line scheduling, but enables better assembly times. In this study, a multi-robot assembly cell was built in graphical simulation software called ROBCAD, and then simulated under different scenarios.

Hsu and Fu (1995) developed a new methodology for modelling, programming and scheduling a multi-robot assembly cell. This methodology integrated scheduling with simulation in two steps. Firstly, an AND/OR graph approach was proposed, to generate all feasible assembly sequences, and secondly, an optimal sequence of product was determined via applying a search algorithm. They built a multi-robot assembly cell by CimStation simulation software, to detect whether any collisions could happen between robots in the cell.

Basran et al. (1997) developed a flexible agent based framework for managing and operating multi-robotic assembly cells. The agents used a contract-net protocol for dynamic task allocation of assembly operations. The study divided an assembly operation into two separate stages: part fetching and part assembling. They considered a simulation approach to validate the proposed framework. The crucial shortcoming of this work is that collision avoidance between robots was completely ignored.

2.4.3 Expert System Approaches

Expert system approaches are among the artificial intelligence (AI) approaches. The basic idea of expert system approaches is to transfer the knowledge from a human to computerized systems. These systems have the ability to analyze a complex problem and recommend practicable solutions (Liao 2004). In recent years, expert systems have been extensively used to solve scheduling problems in several domains; however only three studies have been devoted to solving scheduling of RFAC.

Van Brussel (1990) proposed a knowledge-based system for scheduling flexible robotic assembly cells which incorporates task scheduling levels and real time control levels. The proposed system had the ability to create on-line scheduling by execution and monitoring of the assembly activities for a production order, from the beginning of the scheduling process to the last second the products are completed. Even though the system has the ability to schedule multi-products, no numerical examples were considered in this work.

Del Valle and Camacho (1996) proposed an expert system based approach for finding the best assembly planning and scheduling for a product in a multi-robot cell. The suggested approach was used off-line to obtain a feasible assembly plan using And/Or graph representation. The required times to change the robot tools were considered in this approach. The objective of this study was the minimization of cycle time (makespan). The results demonstrated the performance of the proposed approach with different product types.

Lee and Lee (2002) developed a strategy for scheduling and coordinating the robot tasks in a multi-robot assembly cell. They considered different types of robot tasks, namely move, tool change, pick up and assembly. They built a supervisor controlled logical system using a Petri net representation to prevent collisions between robots in a shared area. The purpose of this study was to minimize the total time of robot tasks required to assemble the final product.

2.5 Research Limitations

The literature review in Sects. 2.3 and 2.4 revealed significant limitations in the scheduling of RFAC. These limitations can be placed into three different categories: *single-product*, *static situation* and *single-objective*, as follows:

- *Scheduling of RFAC in a single-product assembly environment*: Even though the RFAC is able to assemble more than one product, the major limitation of all the studies of scheduling RFAC is that they concentrated on assembling only one type of product at a time. Therefore, there is a need for research that is related to scheduling of RFAC in a *multi-product* assembly environment.

- *Scheduling of RFAC in a static situation*: Even though the manufacturing systems in real industrial situations are essentially facing dynamic events, the second limitation of all the studies of scheduling RFAC is that they focused only on static situations without considering any dynamic events. Ouelhadj and Petrovic (2009a, b) stated that the dynamic events may cause deviations from the generated schedules, and the schedule plan may become impractical to implement when it is released to the system. Consequently, the *dynamic scheduling* of RFAC must receive further attention due to its ability to respond to the unexpected events and to provide effective solutions to real-world applications.
- *Scheduling of RFAC in single-objective optimization problems*: A number of research studies into flexible systems have attempted to optimize those scheduling problems with multi-objectives. However, nearly all the studies of scheduling RFAC are devoted only to solving single-objective optimization problems. Most of these studies used time-based objectives to evaluate the RFAC performance (e.g. Lee and Lee 2002; Marian et al. 2003). Thus, *multi-objective* functions, including time-based and due date-based objectives, need to be simultaneously optimized.

In summary, the research efforts made so far on the scheduling problems in RFAC are inadequate. Some significant issues such as *multi-product* assembly, *dynamic scheduling* and *multi-objective* optimization problems are ignored in the existing literature of RFAC, which need to be considered in the future investigations.

2.6 Research Objectives and Thesis Plan

In order to cover the research limitations in the existing literature and to find the optimal solution for the scheduling problems in RFAC, the research objectives and the plan for reaching the objectives need to be identified clearly. The research objectives and research plan of this thesis are elaborated in the following sub-sections.

2.6.1 Research Objectives

The main objective of this research is to develop a new framework for optimization of the scheduling problems in RFAC which incorporate the important issues in this area such as *multi-products*, *dynamic events* and *multi-objectives*. Due to the complexity of achieving this goal, the research objective is divided into three sub-objectives in the course of this study.

The first objective of this research is the scheduling of RFAC in a multi-product assembly environment. Consequently, this objective will overcome the major limitation in the existing literature; that it concentrates only on assembly of one type of product at a time. To achieve this objective, the following steps must be performed:

- Study the existing methodology for solving the scheduling problems in manufacturing systems.
- Develop a new methodology for multi-objective scheduling problems using intelligent technique.
- Apply the proposed methodology for solving the scheduling problems in RFAC.
- Compare and analyze the results of the developed methodology in relation to the common scheduling policy.

The second objective is the scheduling of RFAC in a dynamic situation. The aim of this objective is to examine the behavior of RFAC under dynamic events and to reflect more realistic scheduling problems. Therefore, this objective will handle the limitation of the previous studies which concentrate only on the static scheduling of RFAC. To achieve this objective, the following steps must be accomplished:

- Study the factors in the literature that have been used to solve dynamic scheduling problems and then extract the important scheduling factors that may cause deviations from the generated schedules in RFAC.
- Propose an intelligent approach for scheduling RFAC in a dynamic situation using advanced solution techniques.
- Implement the proposed approach in a scenario-based case study of RFAC, and carry out an experimental study.
- Analyze the simulation results to examine the behavior of RFAC under different scheduling factors.
- Predict the most significant scheduling factors which affect the system performance.

The third objective of this research is the optimization of dynamic scheduling for multi-objective problems. Hence, this objective will fill the gap in nearly all the relevant literature that used only one objective to evaluate the output of scheduling RFAC. This objective will also lead to improved scheduling in RFAC when two or more objective functions are simultaneously optimized. To achieve this objective, the following steps must be completed:

- Study the methods that have been devoted to solving multi-objective optimization problems in real world applications.
- Design a decision support system for solving multi-objective optimization problems.
- Develop a hybrid approach, using a combination of advanced solution methods.
- Demonstrate the applicability of the developed approach via a realistic case study.

- Analyze the results of the developed approach to predict the optimal combinations of scheduling factors to optimize the objective functions.
- Verify and validate the results obtained, through a sensitivity analysis and confirmation test.

2.6.2 Research Plan and Thesis Structure

In order to meet the research objectives described in the previous sub-section, a comprehensive research plan is required for finding an optimal solution to the scheduling problems in RFAC. In this study, the research plan is divided into three stages, which are stated below along with the procedures taken to achieve them. An outline of the chapters comprising this thesis is also presented in this section.

Stage 1: New methodology for solving scheduling problems in RFAC

In the first stage, a new methodology for scheduling RFAC in a multi-product assembly environment will be developed. In this methodology, a fuzzy-based mathematical model will be combined with simulation modelling to generate an efficient schedule for assembling more than one product at a time.

The developed methodology will be divided into three modules: *pre-processing*, *scheduling* and *simulation*. In the *pre-processing* module, the parameters, objective functions, constraints and decision variables of modelling the scheduling problems in the RFAC will be defined. In the *scheduling* module, the schedule for assembling multi-products will be generated via a new scheduling rule, namely fuzzy sequencing rule (FSR). In the *simulation* module, a computer simulation model of the RFAC will be built using simulation software, and then simulated under different scenarios. The detailed construction of this new methodology will be presented in Chap. 3.

The verification of the methodology's usefulness and effectiveness will be performed via an extensive example application and then the results obtained by the methodology will be analyzed and discussed. The application and results analysis will be explained in detail in Chap. 4.

Stage 2: Development of an approach for scheduling RFAC in a dynamic situation

In the second stage, a new approach for the dynamic scheduling of RFAC will be proposed. The developed approach will be divided into four phases: *preparation*, *Taguchi method*, *simulation modelling* and *statistical analysis*.

In the *preparation* phase, the scheduling problems, objectives, scheduling factors and the number of levels for each factor will be identified, and each scheduling factor will be assigned three levels, because the influence of these factors may vary nonlinearly. In the *Taguchi method* phase, the number of possible experiments will

be determined on the basis of the number of factors and their levels. The benefits of using Taguchi optimization method are to reduce the minimum number of experiments required for scheduling RFAC and to gain better understanding of the impact of the scheduling factors on system performance. In the *simulation modelling* phase, the RFAC will be built as a computer model to evaluate their performance. In the *statistical analysis* phase, analysis of mean (ANOM), relative percentage deviation (RPD) and analysis of variance (ANOVA) will be conducted. The ANOM and RPD will be used to determine the optimal level of each scheduling factor based on S/N ratio results; the ANOVA will be applied to determine the most significant scheduling factors in terms of their contribution to the objective functions. The detailed framework for developing the new approach and its application to a realistic case study of RFAC will be presented in Chap. 5.

Stage 3: Development of an optimization approach with multi-objective problems

In the last stage of this thesis, an optimization approach for multi-objective problems in dynamic scheduling of RFAC will be developed. This approach will be based on hybrid techniques: the fuzzy decision support system (FDSS) and the fuzzy analytic hierarchy process with the fuzzy technique for order preference by similarity to ideal solution (FAHP-FTOPSIS). In FDSS, a computer-based system will be designed using the Matlab fuzzy logic toolbox. In FAHP-FTOPSIS, the FAHP and FTOPSIS will be integrated to optimize the dynamic scheduling in RFAC under different objective-functions. The developed approach will be divided into three phases: *problem description*; *application of fuzzy MCDM*; and *analysis of the results*.

In the *problem description* phase, the hierarchical structure of any MCDM problem will be defined. This hierarchy is constructed based on the overall goal, criteria and sub-criteria (objective functions), and the decision alternatives (feasible solutions). In the *application of the fuzzy MCDM* phase, the FDSS and FAHP-FTOPSIS will be applied to evaluate the feasible solutions and make a final decision. In the *analysis of results* phase, the outcomes of FDSS and FAHP-FTOPSIS will be verified and validated. The comprehensive detail of the above three phases that are followed to develop the hybrid fuzzy MCDM approach will be presented in Chap. 6.

A realistic case study will be employed to test the efficiency of the hybrid optimisation approach. The analysis tools such as sensitivity analysis and confirmation test will be performed to verify and validate the results obtained. The case study and analysis of the results will be presented in Chap. 7.

The summary of the research presented in this thesis, the contributions of the research and possible recommendations for future research will be presented in Chap. 8.

The three sub-objectives of this research and the outline structure of the thesis are shown in Fig. 2.2.

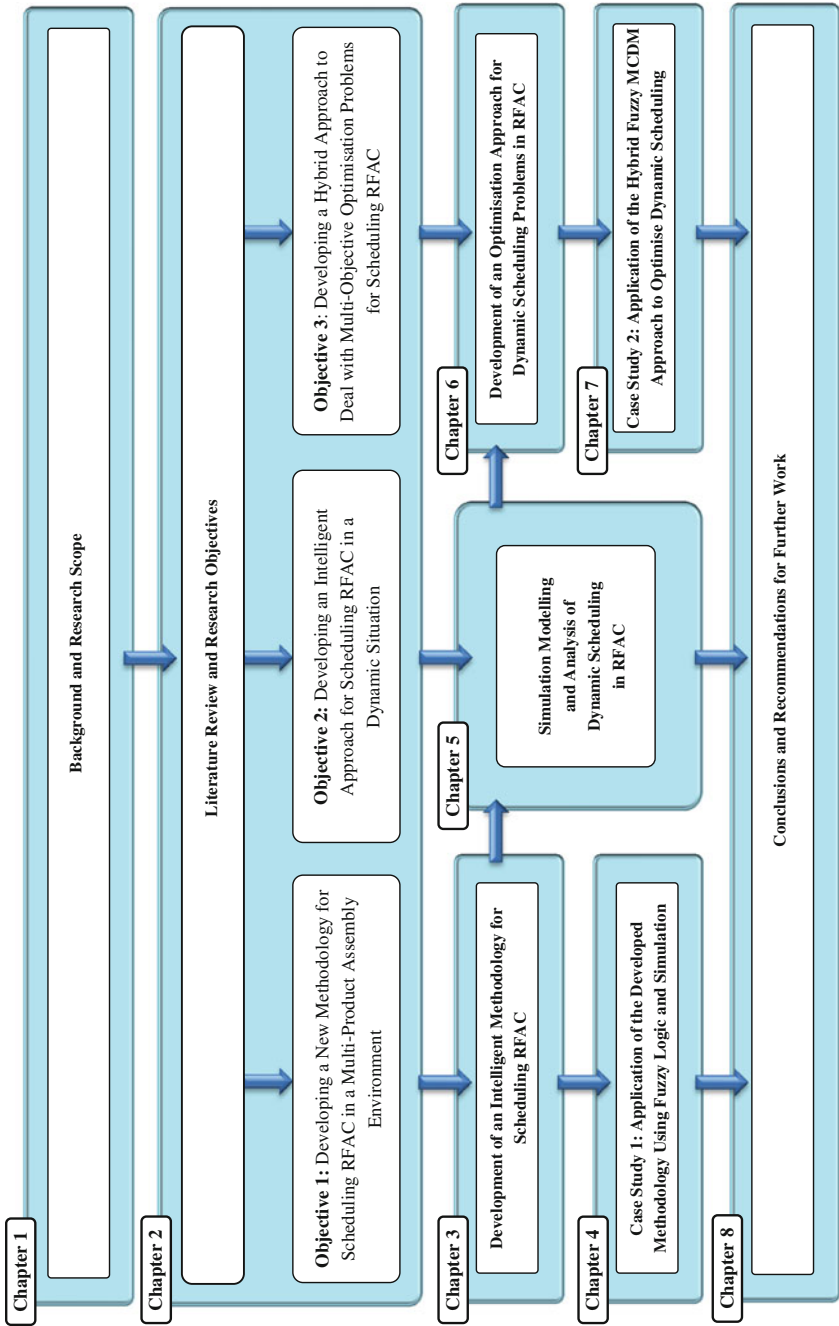


Fig. 2.2 Outline of thesis structure

2.7 Concluding Remarks

In this chapter, the literature on scheduling problems in manufacturing systems was reviewed. This literature review revealed that there has been relatively little work on the scheduling of robotic flexible assembly cell (RFAC), even though overall scheduling problems of flexible manufacturing systems (FMS) have attracted significant attention. The reason for this is because the RFAC requires a complex scheduling system to prevent collisions between robots. Consequently, the decision making in scheduling RFAC is more difficult compared with decision making in the FMS.

In the existing literature of RFAC, three important limitations were identified. First, scheduling of RFAC in a *single-product* assembly environment was considered. Second, scheduling of RFAC only in a *static situation* was investigated without considering dynamic status, which reflects the real world problems. Third, scheduling of RFAC just in *single-objective* optimization problems was examined to improve the RFAC performance. To overcome these limitations, an efficient and novel approach for scheduling RFAC is required to deal with various issues: *multi-product* assembly environment, *dynamic status* and *multi-objective* optimization problems.

From the literature survey in this chapter, it can be seen that there are two approaches to addressing the scheduling problems in manufacturing systems. First, researchers are working towards developing *traditional approaches* to easily find feasible solutions without optimization. Second, researchers are working towards developing *advanced approaches* (e.g. simulation, artificial intelligence) to accurately find optimal or near-optimal solutions. Thus, the main objective of this research is to develop an advanced approach for tackling the scheduling problems in RFAC. In the course of the research, the proposed objective is divided into three sub-objectives: the first objective is developing a new methodology for robust scheduling of RFAC in a multi-product assembly environment (Chaps. 3 and 4); the second objective is developing an intelligent approach for scheduling RFAC in a dynamic situation (Chap. 5); the third objective is developing a hybrid approach to deal with multi-objective optimization problems for scheduling RFAC (Chaps. 6 and 7).

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