# Adaptive and Dynamic Scheduling for Robust Production Planning

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## I. MOTIVATION

Creating a schedule to perform certain actions in a real-world environment typically involves multiple types of uncertainties. To create a plan which is robust towards uncertainties, it must stay flexible while attempting to be reliable and as close to optimal as possible. A plan is reliable if an adjustment to accommodate for a new requirement causes only a few disruptions. The system needs to be able to adapt to the schedule if unforeseen circumstances make planned actions impossible, or if an unlikely event would enable the system to follow a better path.

To handle uncertainties, the used methods need to be dynamic and adaptive. The planning algorithms must be able to re-schedule planned actions and need to adapt the previously created plan to accommodate new requirements without causing critical disruptions to other required actions.

In a static approach, the schedule for a given time frame is derived from the given information and requirements at the time of planning. In contrast, a dynamic approach involves a continuous planning effort, by updating an existing schedule to adjust for new requirements. Adapting to changes can be achieved by using a combination of strategies to find the best solution for given, and potentially diverse, objectives.

Examples of such dynamic approaches are Multi-Agent Systems (MAS), which consist of multiple independent agents. These agents can offer different strategies and work together to find the best decision for the whole system.

In prior work [3], the coordination of multiple agents for an exploration and mapping task was investigated. The paper also considered the capability of each agent to make decisions on its own in case of communication loss to keep the system operational. This expertise is going to be extended in the direction of planning and scheduling problems.

Heterogeneous production environments can be used as an example for experiments. The machines can differ both in their availability for certain tasks as well as the processing time for the tasks. By introducing uncertainties into the scenarios, the use case gets closer to a real-life environment in which the system needs to operate. The uncertainties could be machine failures or deviating delivery times for necessary resources, as well as changing requirements, like additional incoming orders, cancelled orders, or changed orders that need to be processed by the production environment.

While multiple challenges must be addressed to enable automated planning in complex systems, the envisioned dissertation is based on the following research questions:

- *How can heterogeneous Multi-Agent Systems create robust and adjustable action plans while considering uncertainties in uncontrolled, dynamic environments?*
- *How can the robustness of two individual schedules be explained/compared in different uncertain scenarios?*

Following is the description of the topics which will be the starting point to answer the research questions. As the research and experimentation within these topics moves along, additional topics may be added and investigated.

## II. DYNAMIC TASK ALLOCATION

In a heterogeneous MAS, not every available agent is equally suited to perform an action. Due to other scheduled activities, the best-fit agent for a task might not be the best choice. A compromise between choosing the best agent, balancing the workload scheduled by the different agents and the best possible start time needs to be determined. This process should be dynamic and flexible. It would not only accommodate for uncertainties in the information about the current state, i.e., the expected workload but would also allow for some margin in planning to create a robust plan.

### A. State of the art

While Dynamic Task Allocation (DTA) is currently mostly used for multi-robot teams to make decisions on the spot, the same methods can be applied to any scheduling and planning problem to produce a more robust and reliable schedule.

To keep the devised plans dynamic, the system needs to be able to re-plan previously scheduled actions to adapt to new circumstances. This can either be done through partial or complete re-planning of the previously created plan to adjust for newly arriving needs [1, 7].

For DTA, the different actors in the planning environment are usually treated as MAS.

The agents used in a MAS can either follow a fixed strategy or be trained through reinforcement learning or other machine learning methods. In a heterogeneous MAS, the agents used do not necessarily all follow the same objectives or have the same model of the system, which can emphasise different aspects of the problem. Utilising a consensus algorithm, a more robust solution can be found in dynamic and uncontrolled environments [5, 6, 8, 9].

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In addition, a potential MAS could be improved by utilising a meta-system to provide further information and improve the decision-making process.

### B. Objectives and research question

In most research on the topic of scheduling, a schedule is created in a static context. For those cases, it is assumed that all required actions are known at the time of the schedule creation. This includes considerations towards including a planning margin to deal with uncertainties and possible disruptions of the created schedules.

The main objective of examining the topic of DTA for a manufacturing context is to determine if a continuous planning strategy (like used in several Multi-Robot Systems) is viable to boost the robustness of a schedule while maintaining the ability to adjust for possible disruptive events and uncertainties at the time of planning.

The research questions concerning the topic of DTA in the context of planning in a manufacturing environment are

- Are Multi-Agent Systems a viable strategy to introduce robustness into scheduling use cases?
- With what measure can the best compromise between optimal solution and considering possible/probable future events be determined?

### C. Research design and methodology

Experiments with benchmark data will be conducted to determine the feasibility of the approach, using different MAS configurations. The results will be compared to other systems effectiveness. After empirical analysis of the different configurations, the approach will be evaluated using real-world examples.

## III. Adaptive Planning

As opposed to the proactive scheduling with DTA, Adaptive Planning is intended to handle changes to a schedule as a reaction to new circumstances to improve the flexibility and robustness of a devised plan. The new requirements can change what the best plan of action would look like. This way, considering predictions and other uncertain information becomes more viable and less risky for the planning of required actions.

### A. State of the art

When new information or additional requirements arise during planning, the existing plan can become inefficient. To accommodate for that, the initial planning process should take uncertainties into account. This can either be based on historical data and previously extracted patterns, domain knowledge, and risk assessments [2, 4].

Using data and predictions to plan with a margin for adjustments introduces other uncertainties which may result in inefficient plans. For example, if an action is delayed because a possible disruption prevents a better starting time and the disruption does not happen at all, the action will be performed at an inefficient time. To avoid this, a devised schedule should be adjustable. Ideally, only small adjustments should be made to the schedule. This would introduce higher efficiency, facilitate planning with the schedule, and increase the reliability of the schedule [1, 2, 4].

### B. Objectives and research question

The objective concerning Adaptive Planning is to determine a generically usable strategy to balance flexibility and robustness of a schedule, to make sure a devised schedule can be reliable while staying adaptable. Additionally, re-planning an entire schedule for minor adjustments is inefficient and should be avoided, which means more efficient methods should be found. This leads to the research questions:

- How can a compromise between flexibility and robustness look like?
- How can schedules be adjusted effectively to achieve a good schedule while avoiding disruptive changes to unrelated actions?

### C. Research design and methodology

Different approaches for Adaptive Planning will be compared using benchmark data. The most promising approaches will be applied to real-world problems for evaluation.

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