JOB SHOP SCHEDULING AND HEURISTIC OPTIMIZATION

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Abstract:

It is predicted that job shop type of manufacture will be used more than before due economical circumstances. Companies are forced to provide their customers with large variety of products in low volume production, with view of different requirements from product consumers and low stock levels.

This article briefly reviews jobs shop scheduling techniques and present designing scheduling application for SME (Small and Medium Enterprises). Application with heuristic optimization is tested on theoretical problem. Influence of additional constraints as setup times and shift work are considered to get close to real world cases.

INTRODUCTION

Most of companies are focusing on streamlining their processes by implementation Lean methods. Field of planning and production scheduling is often underestimated. Nevertheless design of plane and following schedule in the field of workshop management is one of the critical problems.

1.   PLANNING CONCEPTS

There are contending claims for manufacture as meeting due dates, minimizing stock, makespan and maximizing machine utilization. Reaching these requirements depends heavily on planning and scheduling concept used in the company analyzed below.

1.1   Manual Scheduling

Manual scheduling is used, against assumption of today "IT" world, more often than we can expect. It is used in job shops where scheduling is not consider as important issue. It is more planning than scheduling in this case.

Schedule eg. plane is than based on:

- Average lead times (e.g. two weeks) not respecting production constraints, requirements etc.
- Job start times are based on actual material availability and forecasted end times of precedence jobs.
- Handmade calculations made to prolong loading time, in case of known bottlenecks.

Process is than driven by natural based FIFO rule insured by waiting lines at the workstations. Manual scheduling than leads to high WIP (Work In Process), high makespan and consequently "firefighting". Firefighting is usually based on demands whose has most

critical delay of due time or makespan. Giving the highest priority to this demand without knowing consequences to schedule delay usually more jobs than one.

Usual solutions are incretion of work capacity, which leads to greater scheduling problem, or converting from job shop to product oriented processing line, which leads to smaller variability of production system and higher production cost.

1.2 White boards and spreadsheet programs

Many companies are still use whiteboards for production scheduling purpose. This method could is sufficient for small and simple production systems. But, it is not practical for scheduling large amount of diverse jobs. Many software vendors extended the whiteboard concept by offering an electronic version, which offers manual schedule construction and modifications on Gantt chart (on computer screen).

The most used application of electronic whiteboard is thanks to Excel spreadsheet. The applications are designed to make feasible schedule thanks to possibilities given by VBA (Visual Basic for Applications). However, scheduling complexity of many job shops is so high that Excel applications fail to meet the requirements for quick rescheduling and what-if analysis. A significant disadvantage of Excel applications for scheduling hundreds of diverse jobs is the large execution time needed for generating a feasible and meaningful schedule. Following disadvantage is time cost of possible optimization algorithms.

1.3 Scheduling in resource planning environment

Implementations of sophisticated enterprise-wide integrated information systems, which are known as ERP (Enterprise Resource Planning) systems, are really popular. Companies are able to handle all their information very easily and improve the efficiency of business operations with the help of these systems. The utility of ERP systems has further increased in manufacturing execution due to the integration of shop floor data collection systems with a central database. From a customer relations point of view, these systems enable the industries to promptly give their customers real-time job status.

1.3.1 ERP/APS and MES

However systems, based on MRP (material resource planning) are not capable of job shop scheduling. Problems with production scheduling are usually solved by before mentioned spreadsheet planners or APS (Advanced planning and scheduling) systems.

These systems which get data about shop floor model from TPM (Technological Preparation of Manufactory) e.g. BOMs (Bill Of Materials) sometimes provide foramens unfeasible schedules and they are force to repair schedule themselves. Without knowledge of job shop scheduling is drag and drop rescheduling quiet time consuming.

Powerful ERP/APS, while securing material availability, are usually based on classical scheduling priority rules as customer demand and SPT (Shortest Processing Time) or MWKR (Most WorK Remaining) [1], without possible foreman intervention securing feasible schedule in one side and disabling possible schedule optimization on other side.

Great problem of APS systems is area of use. APS system is often used in the long term scheduling due high cost of APS and time span of scheduling whole manufacture. Foreman has little influence to this schedule. MES (Manufacturing Execution Systems) are suitable for local optimization of detailed schedules in workshops and they use ERP information as APS systems.

1.3.2 TOC scheduling

One of the methods for production scheduling in complex job shop is Drum-Buffer-Rope (DBR) method of the TOC (Theory Of Constraints). DBR scheduling method is based on assumption that a production system has a single resource constraint and the other resources have sufficient capacity to fully support any feasible schedule on the constraint resource.

DBR concerns with a single constraint resource enables foreman to schedule jobs on the constraint resource ignoring the capacity of all non-constraint resources. It is not always possible in the complex job shop due shifting bottlenecks. However one of most used schedule optimization tools is OPT (Optimized Production Technology) system, which is scheduling in scope of DBR method. OPT optimize lot sizes and sequences of jobs on critical constraint (e.g. bottleneck) thanks to knowledge of the machining model as alternative technological orders, interchangeability of machining devices and sequence dependent setup times. Scheduling problem in view of TOC is also solved with large variety of shifting bottlenecks algorithms [2][3][4].

1.3.3 Lean TPS scheduling

TPS (Toyota Production System) is world-class production system, which developed and put in practice many concepts, principles, practices and methods Heijunka together with Kanban is suitable for controlling repetitive production, prevents lack of work at bottleneck work places and reduce large inventory at any work place by regulating the material flow through the production system. Kanban based systems are not very suitable to solve scheduling of job shop based manufactory systems in other side. Kanban system cannot provide the predictability of workflow and job completion times for job shops with diverse jobs that move through different sequences of work centers. It is useful for production management thanks to two card [5] and other "card" systems as POLKA [6] [7], but is very hard to use for prediction and what-if analysis.

1.3.4 Simulation

Simulation is one of most powerful tools in the view of production and manufacture system design with long tradition of job shop scheduling [8]. Its usage is mostly as what-if analysis together with its ability to describe process constraint as accurate as user is able to. Its weakness is in data storage and material resource planning. Also production scheduling is not available in every simulation systems. It is usual that simulation systems can provide us with large amount of stats beginning with machine (worker, setup gigs) utilization and ending with WIP, but it is not usual to get feasible schedule.

Nowadays simulations become part of PLM (Product Lifecycle Management) systems as Delmia or Technomatics, with ability to ensure production management together with optimization of manufacturing system in the view of combinatorial problems as job shop scheduling. Production scheduling and schedule optimization is still rare. However there are promise schemes [9] and systems [10] of simulation scheduling not only in job shops [11].

Great advantage of these systems is ability to use various types of job shop (hybrid, flexible) but there are sometimes unable to reach optimum due their ability to generate only non-delay schedules, which are not always optimal.

1.3.5 Scheduling algorithms

Researches published lot of books and articles about heuristic for JSSP (Job Shop Scheduling Problem). These articles are focused to optimize objective function of makespan, due dates WIP in scope of JSSP.

However, these algorithms have these problems:
- Focusing just on minimizing makespan (due date) of theoretical problem, which are in the view of practical problem too general.
- Focusing on problems as complex as is it possible (sequence dependent setup times)
- Algorithms are that complex with great variety of setups that are hard to set for usual foreman or planner.

2.   USAGE of OPTIMIZATION METHODS for JSSP in SME

The possibilities to solve job shop type of manufacture are wide as it was described. There are great opportunities in the view of spreadsheet planners, ERP/APS and Scheduling algorithms. It can be assumed that most of foremen in SME industry met spreadsheet planers or ERP/APS systems but they are not familiar with Scheduling algorithms and optimization methods. The goal is to develop scheduler, which meets required constraints of real job shop manufactures and aid of optimization methods, which can be used without foremen knowledge of their mechanism.

Concept of this scheduler is based on spreadsheet modeling where the schedule is made by scheduling application with aid of optimization methods (Figure 1)
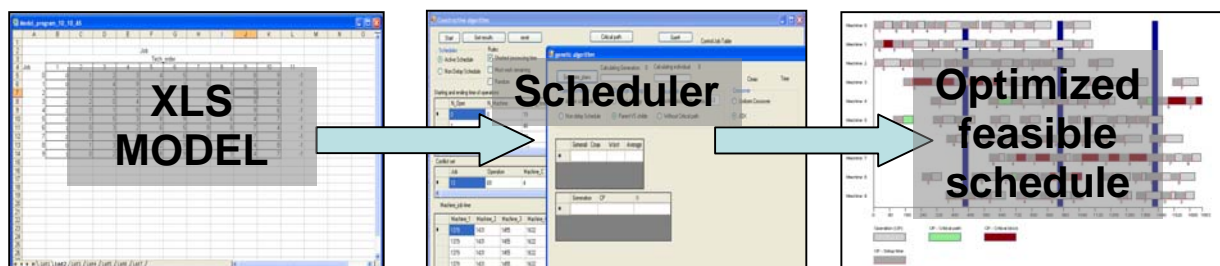

Figure 1 Scheduling concept

The goal is not to manage manufacturing production but offer optimal schedule as far as it possible. There was made several tests of optimization methods with aid of Giffler and Thompson CA (Constructive Algorithms) using priority rules, LS (Local Search) and GA (Genetic algorithms) on job shop theoretical problems [12][13]. Work is focusing now on real job shop problems with their constraints meeting dates available in usual SME company.

2.1   Independent and dependent setup times

Considering setup times in heuristic optimization is long known "real" problem, which can be generally divided to independent setup times and dependent setup times.

Independent setup time heuristic is not influenced by order of jobs on machines, which is not usually accurate in the matter of real constraints. Every time we setup machine we must

consider also possible time to "un-setup" machine, so we can again setup machine for new job.

The problem is in the "real case problems", which theoretical problems don't recognize. Companies use setup time for scheduling, which depend on technological order, where are setup times with times to "un-setup" are summed together without considering job sequence on machines in better cases.

Recent research makes great deal in independent setup time heuristic [14] [15], and is useful for cases, where companies have greatly described theirs processes and have huge database of dependent setup times.

2.2 Setup times and pass-setup

We focus on constructing solution with independent setup times especially so-called "pass-setup". In the matter of single setup times is constructing solution very easy. Only thing that we do is simply sum setup time with processing time to get overall time that job will occupy machine. So we need only additional information about setup time length respecting job and machine, same as in the process time

Pass-setup is possible when we can make setup without precede job complete. This is usually possible thanks to setup tools, jigs, standard parts etc. The goal is to make account of unused time on machine minimizing makespan, total flow time, total weighted flow time etc. Key thing considering Giffler and Thompson algorithm is to set correct starting time of both setup and process. For this we need to gather information about available machine starting times and end times of precede job.

2.3 Shift work

Shift work, which is typical mainly for manufacturing organization, has clear impact to function of a company. We can increase production up to 300%, compared to day shift system, by using 3-shift system. It has also impact to utilization of manufacturing resources (machines). Another reason are (typically in automotive, chemical, metallurgic and textile industry) expenses bounded with stopping and restarting manufacture.

Significant disadvantage of work shift system is beside high requirements to labors, especially in the night and morning shifts, demanding scheduling. Typical shift work system is 3-shift system with 8 resp. 7.5-hour shifts. This system unusually used in two modifications -morning shift begins at noon (0:00) or at 22:00. Shift work setting is also depending on company culture, which is usually taken up from foreign countries resp. "mother companies".

There are taken in account different Shift work systems, in the projected application, with these parameters:
- Number of shift in a day
- Duration of shift
- Duration of brake
- Beginning of the first shift

It was chosen theoretical hard job shop problem FT20 [16] for testing before mentioned constraints. This problem was modified to exploit new possibilities of modified algorithm.

Modifications are than:
- Time units (process times) are set to minutes,

- Implementation of setup times – every operation is available only after setup with duration of 50 minutes,
- It was used pass-setup system for testing,
- It is used 3-Shift work system with shift duration of 8 hours (resp. 7,5 hours) with half hour break duration. The first shift begins at 22:00.

Before mentioned methods (Constructive algorithm, Single swap local search, Genetic algorithm) where used for schedule optimization and there was several good results. We get best result thanks to GA.

Schedule can be than represent e.g. by Gantt chart (Fig. 2 and Fig 3. breaks are highlighted by blue).
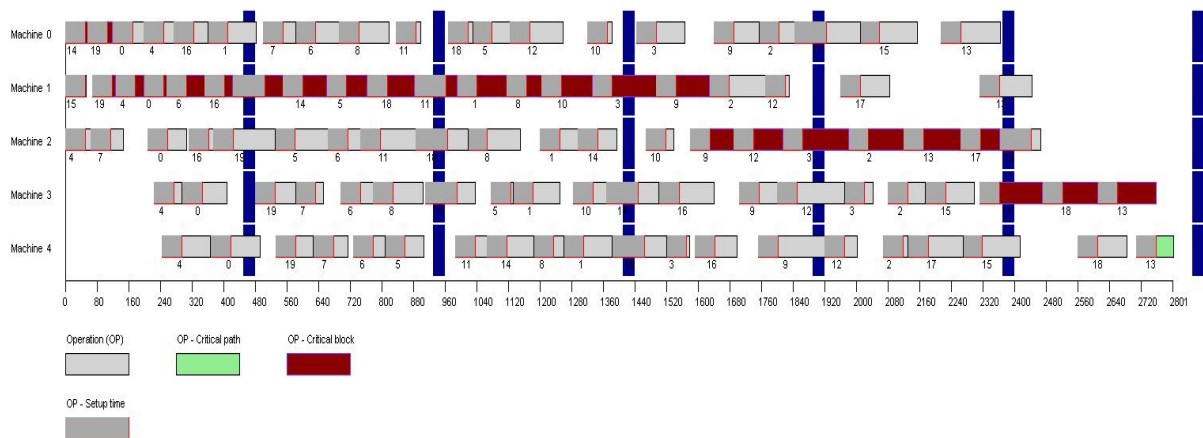

Figure 2 *Schedule created by CA with priority rule SPT (makespan 2801)*
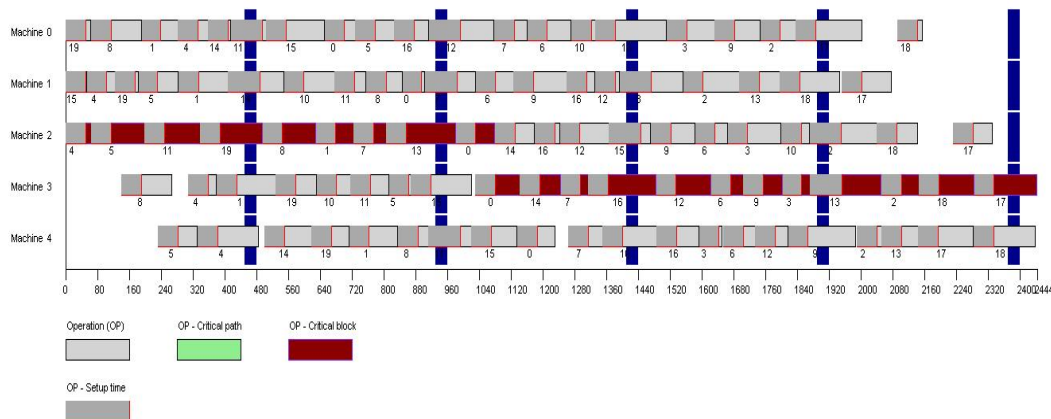

Figure 3 *Schedule optimized by GA (makespan 2444)*

2.4 Manipulation

Manipulation is one of constraint that can influence schedule. However it is very difficult to get real data about manipulation. They are not available in technological order and "processing time" of manipulation is changing frequently. It is not problem to include manipulation in the model. Earliest start time of operation can be influenced thanks to knowledge where precedence operation in job was made and thanks to transportation matrix (Table 1) we can delay starting operation. Nevertheless, application is not with manipulation

due problems mentioned before – companies does not have described and standardized their manipulation processes and calculating with manipulation can negatively influence model.

X	Machine				
	0	1	2	3	4
0	0	5	4	6	7
1	5	0	3	12	21
2	4	3	0	1	18
3	6	12	1	0	23
4	7	21	18	23	0

Table 1 Transportation matrix

3. CONCEPT OF SCHEDULE OPTIMIZATION BY FOREMAN

One of mentioned disadvantages of scheduling algorithms is that they are too far complex to be useful by foreman as optimization tool. The goal is to minimize knowledge, which is required to optimize plan. There are several methods and it´s setting in the view of optimization:

- Type of plane
    - o Active (proceed operation which has nearest ending time of completion)
    - o Non-delay (proceed operation with nearest starting time)

- Constructive algorithm - Choosing priority rule
    - o Shortest processing time (SPT)
    - o Most work remaining (MWKR)
    - o etc.
- Local search based method
    - o Setting initial solution (schedule)
    - o Number of iteration
- Genetic algorithm
    - o Velocity of population
    - o Crossover coefficient
    - o Mutation rate or number of clones (using clone control instead of mutation)
    - o Number of generations

Each of these methods has its advantages and disadvantages in the scope of optimality and required computation time (Figure 4).
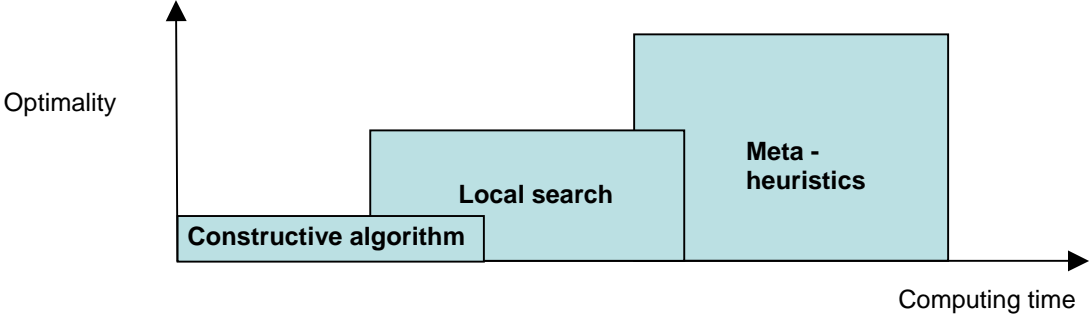

Figure 4 Optimality and computing time of heuristics methods

It is necessary to minimize number of heuristic method setting to only one that is meaningful for foreman – time available for optimization, with respective expectation of optimal schedule.

Constructive algorithms are very fast algorithms and with aid of priority rule can provide user (foreman, planner) with solution immediately. So using rules as SPT and MWKR, which are usual in ERP/APS as mentioned before, will be not time consuming.

From these schedules we can generate thanks to local search techniques more optimal solutions. The question is how to set number of iterations. Knowing that Genetic algorithms are more time consuming but they can provide us with lot more optimal schedule projected scheme will has ending event. Algorithm will end when there is no better solution in new iteration. It will cause very limited search (job shops has lot of local optimums), but it will provide more time to GA optimization.

In case of genetic algorithm can be set as:

- o   Velocity of population = number of operation in the schedule
- o   Crossover coefficient = 0.6 for JOX (Job operation based crossover)
- o   Number of clones = max 10% of population (for faster convergence)
- o   Number of generations = (remaining time) / (time spend for one generation)

As Genetic algorithm is very time-consuming it was decided to use only one of schedule type (Active, Non-delay). Test show that both constructive algorithm and local search has better results (shortest makespan) as non delay schedule but GA has better result as Active schedule in same available time (Table 2).

Table 2 Timed result test

With shift work				
Method	Rule	Active s.	Non delay s.	Time span
CA	SPT	2801	2622	1 s <
	MWKR	3054	2914	1 s <
LS	SPT	2731	2542	2 s
	MWKR	2711	2914	2 s
GA	-	2444	2468	630 s

Test was set to 10 minutes of time span. Result show that test time span was longer that was set. It was caused probably by clone control where identical individuals (schedules) – clones are replaced by another schedules. Number of clones is hard to predict so timing scheme need to be revised. However set time span was prolonged only by nearly 5%.

CONCLUSION

As review of scheduling concept showed not all concepts has ability to solve job shop based production model. Scheduling algorithm can be pretty useful even for practical models in case of well-constrained model. However, constraining model heavily depends on model description - available information about manufacture in the company.

Following research will focus on practical models and their constraints from SME industry together with time efficiency and required time span to get optimal schedule.

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