Applying the Distributed Arrival Time Control for Just-in Time Scheduling in Flexible Job-Shops with Transportation Times

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Agenda

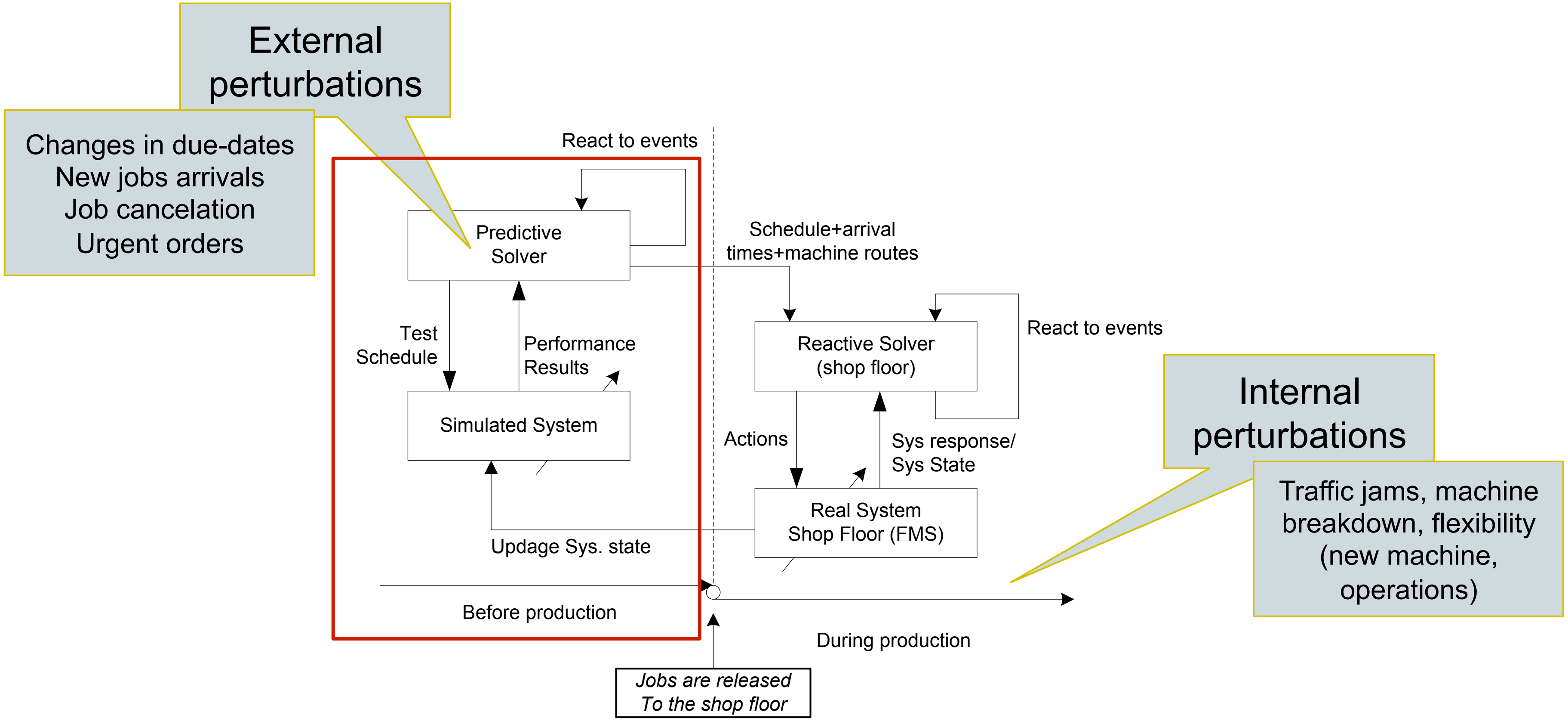
Introduction

- The flexible job-shop problem: complex, challenging problem.
- The Just in Time (JIT) problem: intractable (tardiness in a one-machine is NP-hard).
- Transportation times are regularly neglected: inapplicable results to manufacturing systems.
- Manufacturing control:
  - Adaptation
  - Reactivity.

General Objectives

- To propose a methodology for manufacturing control based on:
  - Predictive/reactive behavior for flexible job-shop problem for Just-in time objectives (MSD)
  - Real constraints:
    - Transportation times
    - Max number of products
    - Machine queuing limitation

The general perspective



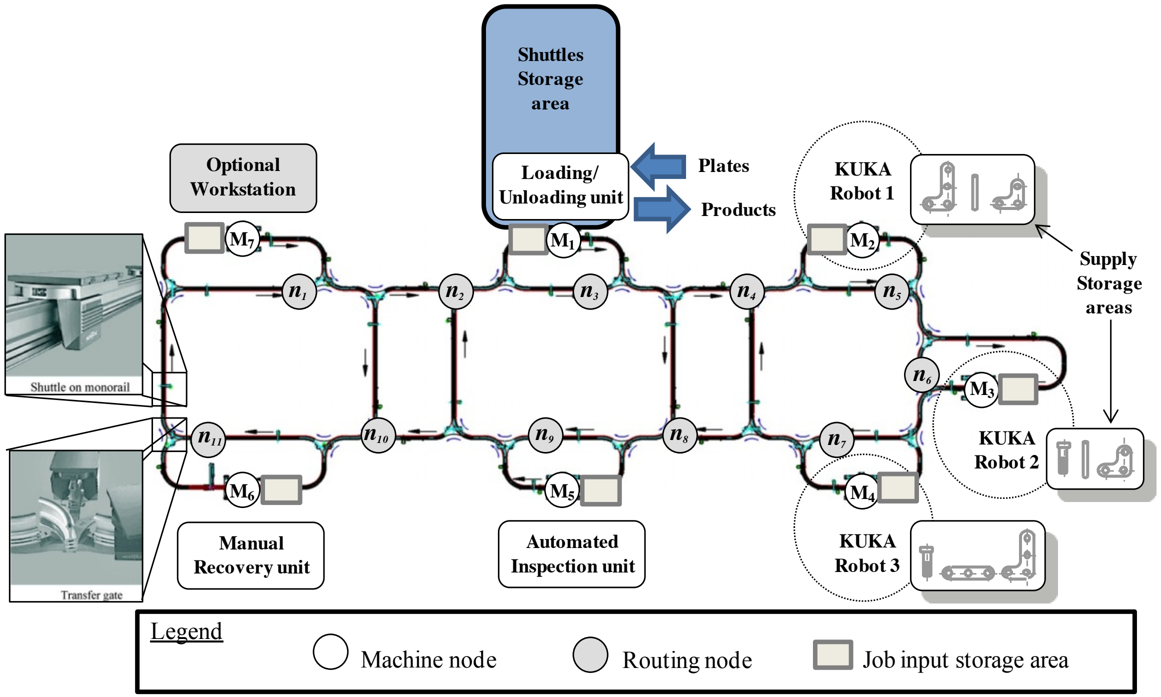
The flexible job-shop problem

- The FJSP:
  - Complex version of the JSP.
  - NP-hard and hardly combinatorial
  - Complexity →Flexibility (Brandimarte, 1993) → machine, trajectory, job, operation flexibility, etc
- *Definition: The flexible job-shop scheduling problem is defined as the allocation of* ***m*** *unrelated resources to* ***n*** *different jobs, that may have different operation sequences with flexibility constraints*
- Applications: real-manufacturing environments, logistics & transport systems

The routing sub-problem:
- ❑ the allocation of each operation to one of the alternative resources

The scheduling sub-problem:
- ❑ The sequencing of the operations on the assigned resources

The transport sub-problem
- ❑ The trajectory used to go from m_{i-1} to m_i



Related works

Type	Author	Approach	Routing sub-problem	Scheduling sub-problem	Obj. Funct	#Max of products	Transport Times	Queue Capacity	Static Case	Dynamic case
FJSP	Brandimarte, 1993	Hierarchical	Tabu Search	Tabu Search	Cmax, Min Weighted	Not considered	Neglected	Not considered	Yes	Not considered
FSP	Prabh, 2003	Hierarchical	FCFS-FAM	Arrival Time Control	MSD	Not considered	Neglected	Not considered	with adaptation	Not considered
FJSP	Fattahi et al, 2007	Hierarchical	Simulated Annealing	Simulated Annealing	Cmax	Not considered	Neglected	Not considered	Yes	Not considered
			Simulated Annealing	Tabu Search						
			Tabu Search	Tabu Search						
			Tabu Search	Simulated Annealing						
		Integrated	Tabu Search							
			Simulated Annealing							
FJSP	Sallez et al, 2010	Hierarchical	MAS-Based (CN) --> allocation		Cmax	Not considered	Considered. Dynamic routing process	Considered. Dynamic allocation	Not considered	Real-time
			MAS-Based (CN) --> transportation							
DFJSP	Giovanni and Pezzella, 2010	Integrated	Genetic Algorithm + refinemen by Local Search		Cmax	Not considered	Neglected	Not considered	Yes	Not considered
FMS	Wang et al, 2008		MAS+ FBS-based heuristic algorithm		minimization of a weighted quadratic tardiness	Considered	neglected	Not intermediate buffers	Not considered	Real-time
FJSP	ttahi and Fallahi, 2	Integrated	GA 2-chromosome (Oper, Seq.)		Cmax and stability	Not considered	Neglected	Not considered	With re-scheduling	Not considered
			MILP		Cmax	Not considered	Neglected	Not considered	Yes	Not considered
JSP	Shaikh, 2003	N/A	Genetic Algorithm + Arrival Time control		MSD	Not considered	Neglected	Not considered	Yes	Not considered

- Mostly **push production** or just **tardiness penalties**.
- **Real constrains** are regularly **neglected**, specially transport times.
- **Release times are zero** or set to a value, but they are not part of the problem (except ATC).
- Normally, **common due-date is just considered**. Different due-dates are normally not considered (except ATC).
- Very **few works** consider both, **the static and the dynamic case**.
- **Hierarchical** algorithms have shown better performance, which is motivation for **hybridization**

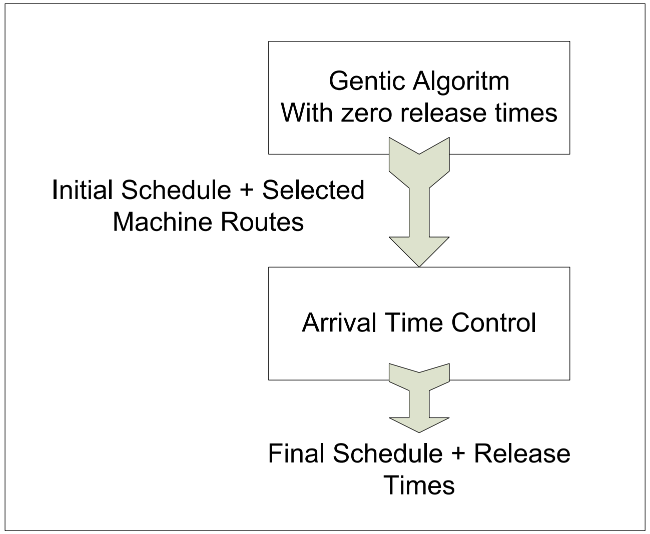
Hybridization

The routing sub-problem:
Genetic Algorithm (coding)

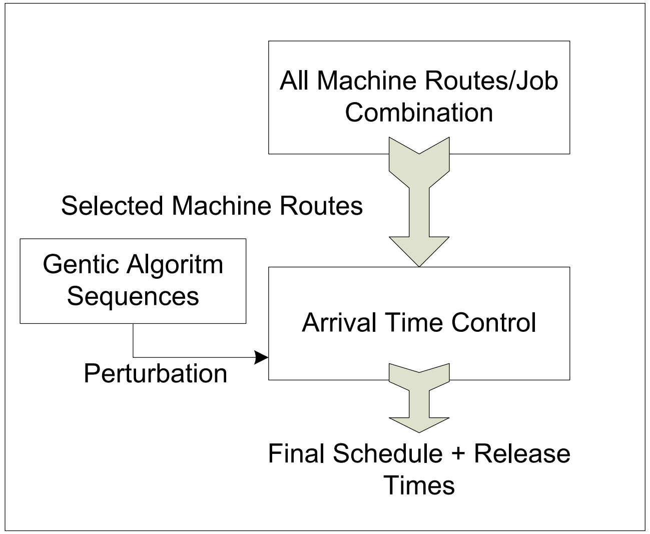
The scheduling sub-problem:
The Arrival Time Control (ATC)

The transport sub-problem
Policy. Shortest Processing Time

Transformation: Flexible job-shop to Hybrid Flow-shop



MSD deterioration



Combinatorial explosion

Hybridization

The routing sub-problem:

Genetic Algorithm (coding)

The scheduling sub-problem:

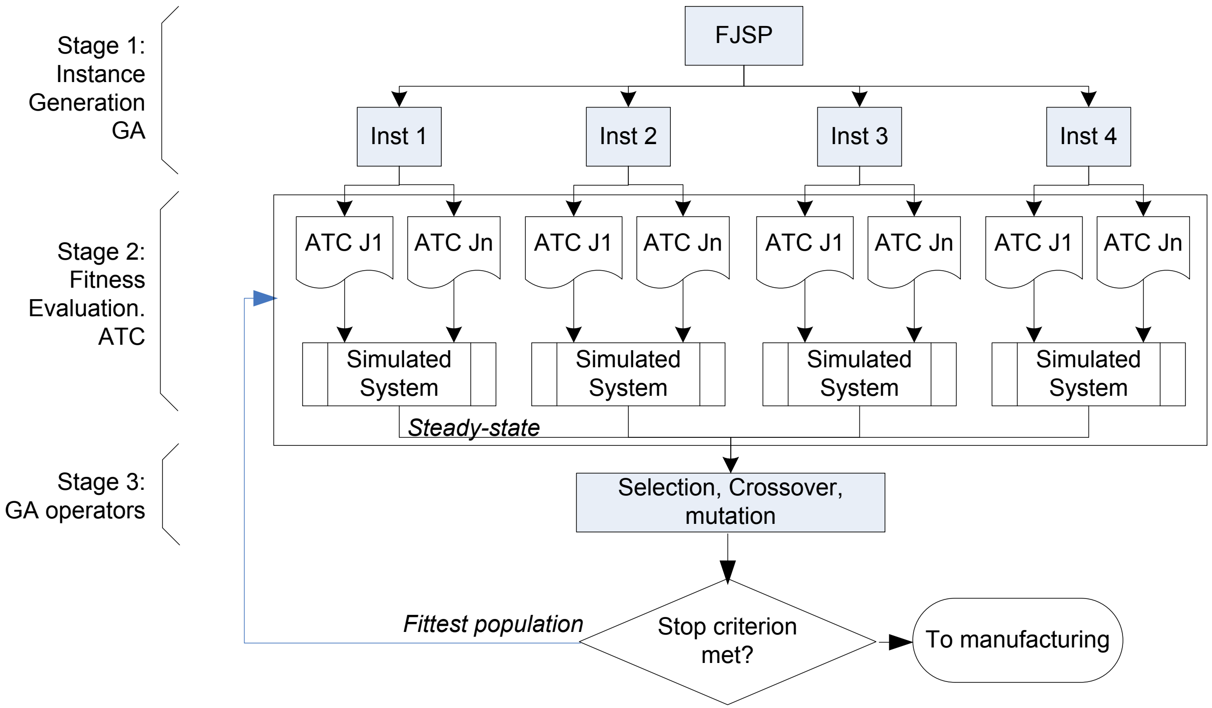
The Arrival Time Control (ATC)

The transport sub-problem

Policy. Shortest Processing Time

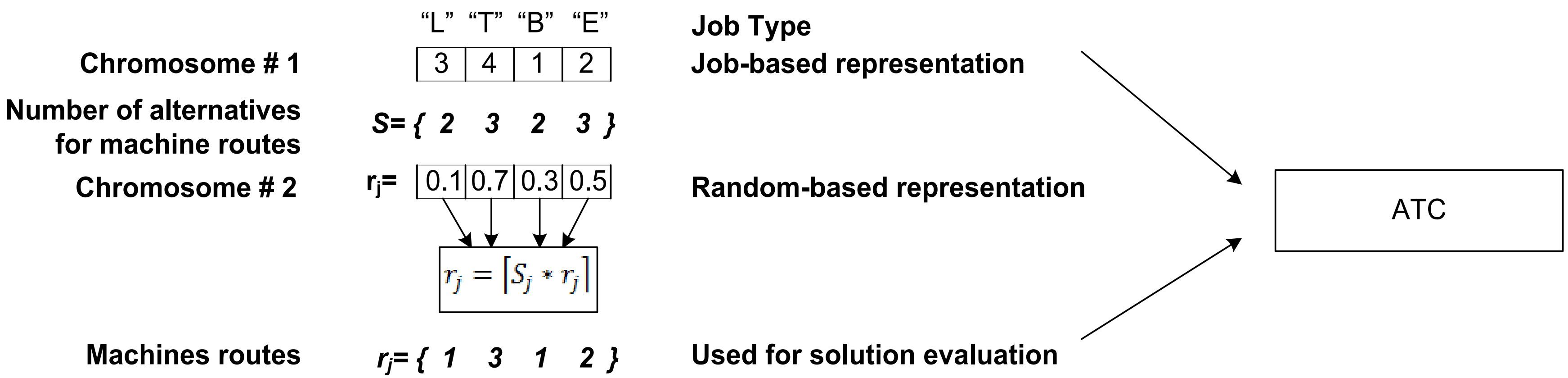
Transformation: Flexible job-shop to Hybrid Flow-shop

- GA: instant generation by a double-chromosome coding.
- ATC: fitness evaluation.
  - Minimization of due-date deviation by continuous adjustment of arrival times (continuous variable).
- SPT: use efficiently the material handling system



The routing sub-problem — Genetic Algorithm

- Double chromosome coding:
  - Chromosome #1: Direct coding. Initial sequence.
    - Force the ATC to visit solutions that it might not visit otherwise.
  - Chromosome #2: fixes a machine routing for each job, among the set of possible machine routes ***S***.
    - Avoid the combinatorial explosion.
    - Indirect coding: independent of the first chromosome (Hussain, 1998)
    - U(0,1).
- Crossover operator: Two-point-cut for both chromosomes.
- Mutation operator: swapping for chromosome #1 and random insertion for chromosome #2.
- Random insertion every λ generation to insert variety into the population and avoid rapid convergence.
- N-best selection policy based on the mean squared due-date deviation (MSD).
- Convergence rule: steady state for the best instance during a certain number of generations.

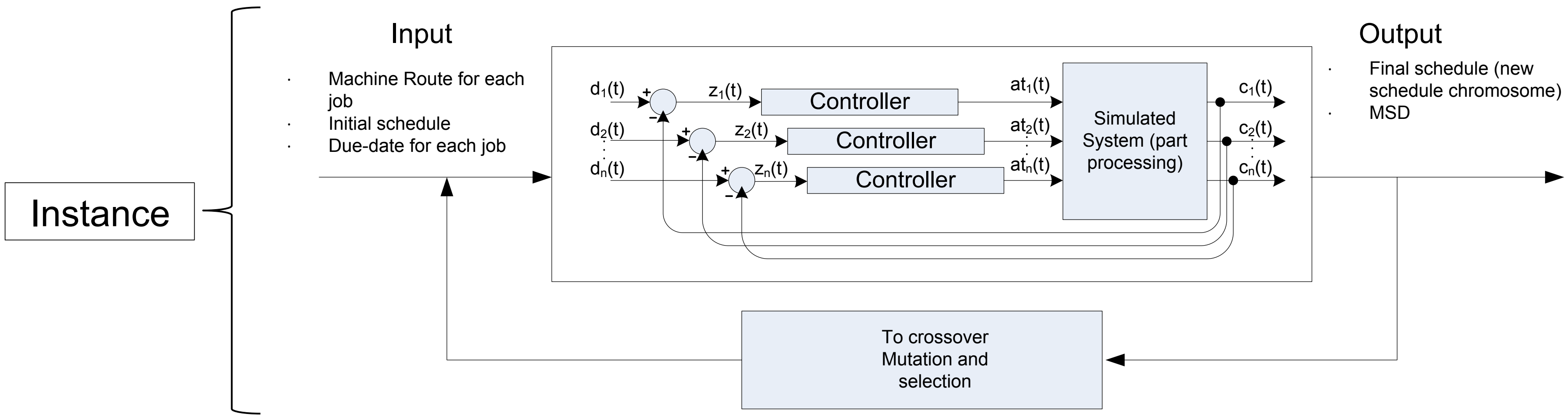


The scheduling sub-problem — Arrival Time Control

- Scheduling method based on control theory.
- Continuous time variable: the arrival times (release time into the cell)
  - Arrival times affect: queuing times, machine idle times and jobs processing order.
- Suitable for Just-in Time production (MSD)

$$at_j = k_j \int_0^t \left(z_j(\tau)\right) d\tau + at_j(0) \qquad z_j(\tau) = d_j - c_j(\tau)$$

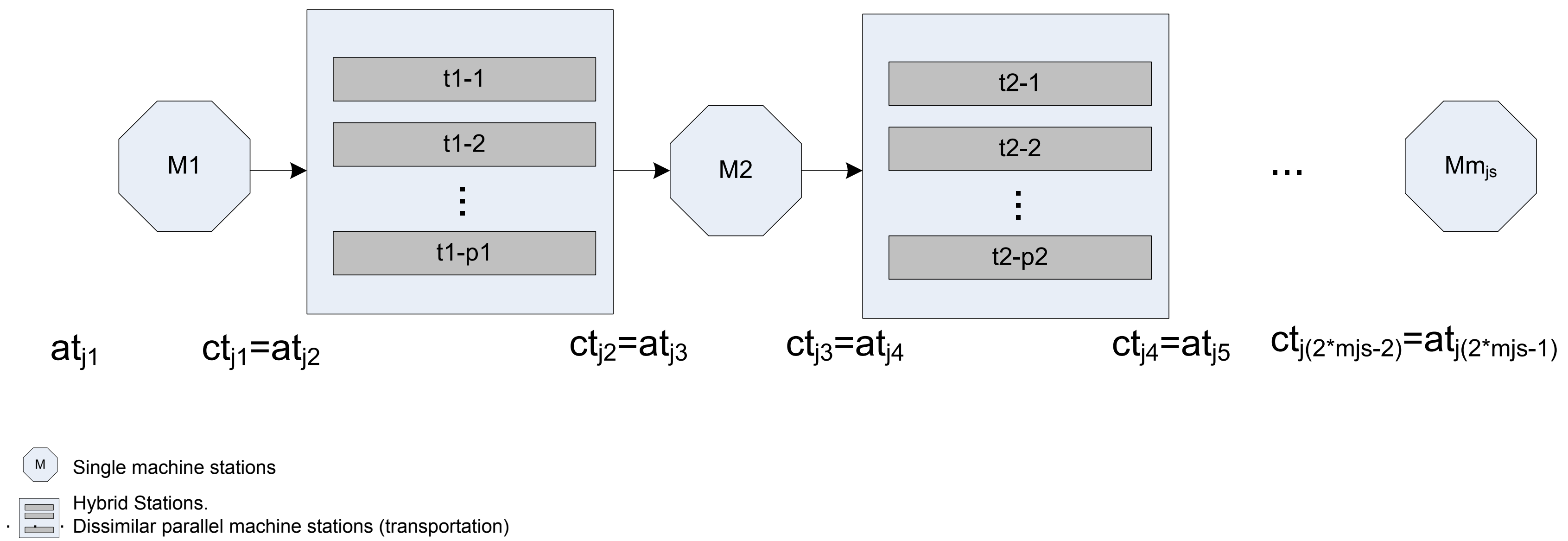
- Highly reactive and adaptable
- Its convergence and stability has been proven mathematically.
- Applications: single machine, parallel machines, flow shop problems.
- Just the static case.



The transport sub-problem

The simulated environment

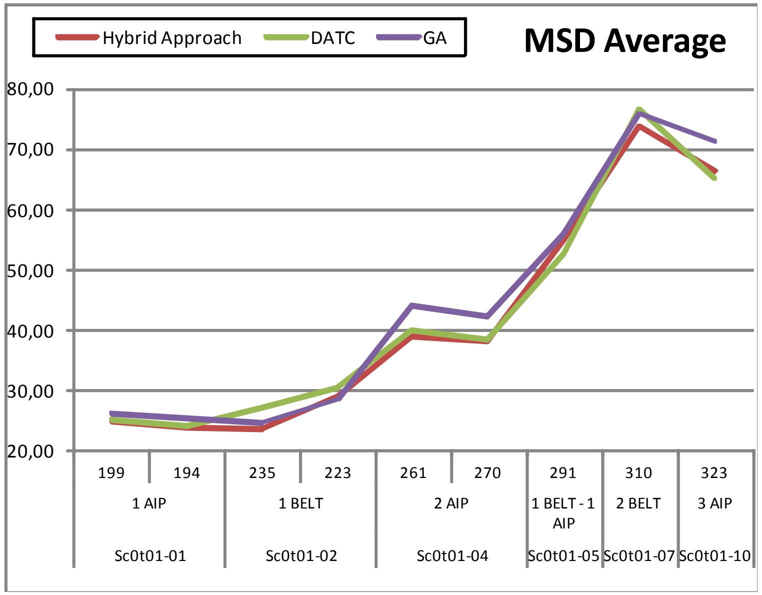
- Each instance → hybrid flow shop
  - Single station: processing machines
  - Hybrid stations: transport services. Dissimilar services (length, times)
- Transportation selection by heuristic policy: shortest processing times
  - Minimization of work-in progress
  - Minimization of machine idle times
  - Energy consumption
- Adaptation to traffic events (e.g. jamming)
- Machine´s queue capacity can be handled by transport times (longer trajectories through inner loops)

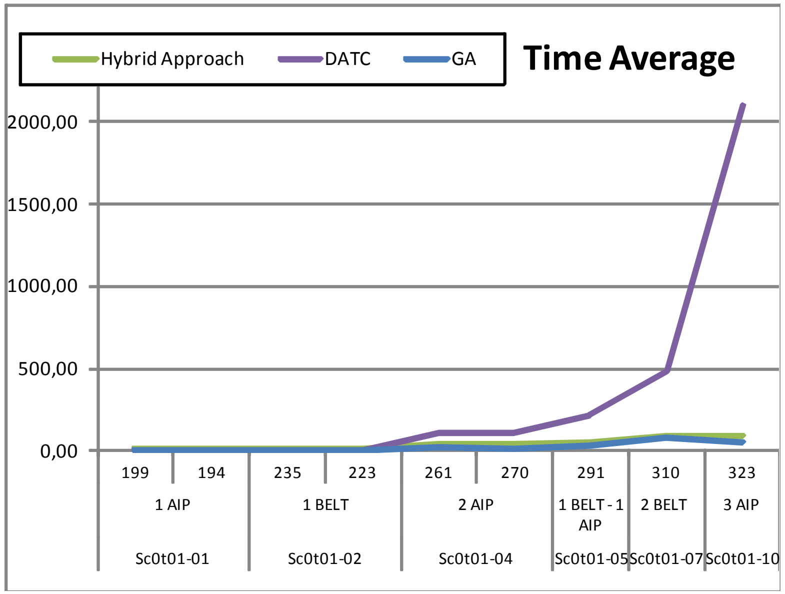


Design of Experiment – The static case

- Objectives:
  - To prove the efficiency of the approach against the non-hybridized versions of DATC and GA
  - To determine its scalability
    - Number of jobs, job variety
  - To determine its computational efficiency for manufacturing control
- Current Implementation: MatLab for windows (Pentium CPU 3.40 GB RAM 1GB)

• Increasing number of jobs: from 3 to 9
• Non feasible due-dates
• Same parameters for convergence (DATC-HA)
• Same crossover, mutation and selection parameters (GA- HA)





Mean of 10 trials per test for the hybrid approach and the genetic algorithm

Design of Experiment – The static case with adaptation

- Objectives:
  - To prove the adaptability and solution efficiency of our approach
  - To determine its responsiveness
- Tests
  - Sc 1→New flexibility: at a certain time *t* a machine is able to perform a new manufacturing operation
  - Sc 2→ Urgent job: at a certain time *t* a new job arrives with the same due-date
  - Sc 3→ Transport perturbation: at a certain time *t* a non-critical transport segment becomes jammed
  - Sc 4→ Machine breakdown: at a certain time *t* one of the redundant machine breaks down

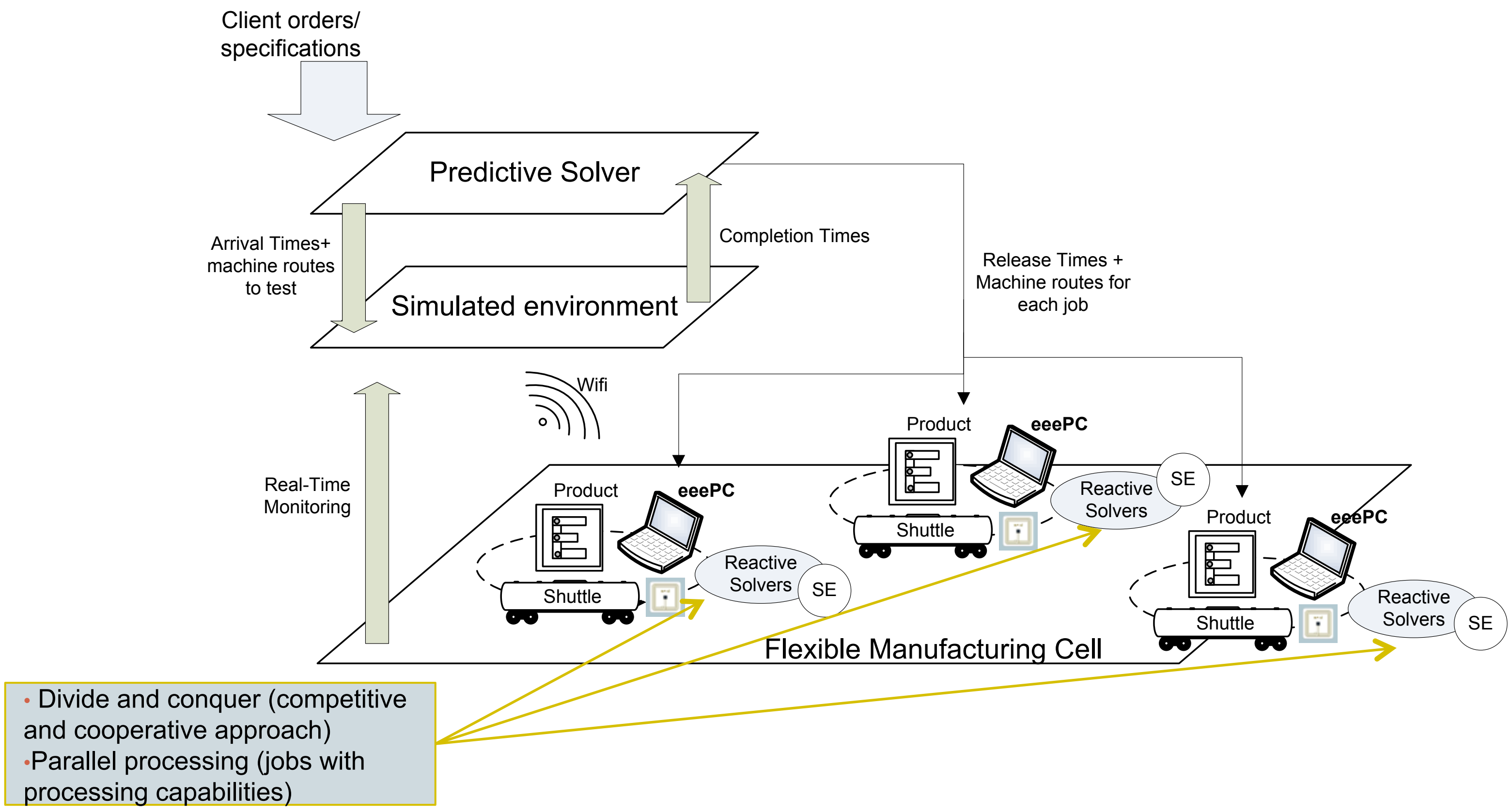
	Hybrid Approach		**DATC**		**GA**	
Order	**MSD Average**	**Time Average**	**MSD Average**	**Time Average**	**MSD Average3**	**Time Average**
Sc 1	25,96	10,36	27,20	26,90	24,80	7,88
Sc 2	78,88	43,45	83,79	199,22	84,26	29,00
Sc 3	24,31	8,90	28,68	8,77	25,39	6,82
Sc 4	99,11	5,10	122,16	2,94	99,11	4,58

Better response

Much less time

Foreseen Implementation

- AIP PRIMECA Flexible Manufacturing Cell
  - 4 Robotic Stations + Inspection + Manual Recovery
  - Product variety (3 products, 7 different types of jobs, 8 different types of operations)
  - Conveyor system: self-propelled shuttles + transfer gates controlled by PLC
  - Shuttle localization by RFID
  - Active jobs = passive job + shuttle + processing unit



Conclusions and further work

- The hybrid approach takes advantage of the best characteristics of each algorithm:
  - Consistent good results with an adequate computational efficiency.
  - Variability of results are less than in the pure version of the GA.
  - The hybrid approach integrates a continuous variable, extending the application of GA to cases requiring release times greater than zero.
  - The hybrid approach enhances the DATC by setting initial job sequences that otherwise the DATC does not explore.
  - The hybrid approach limits the solution space exploration for the DATC, otherwise too costly.
- Transport times, queue capacity and maximum number of jobs are considered
- Adaptation to internal and external perturbation. Good results

Further work

- Speed up convergence of the control loop (rising times of arrival times)
- Population analysis. Certain combinations are known to be inefficient *a priori*.
- Comparison with a quadratic linear program (in progress)
- Validation at the AIP PRIMECA cell

References

- Y. Sallez, T.Berger, S.Raileanu, S.Chaabane, D.Trentesaux. Semi-heterarchical control of FMS: From theory to application. Engineering Applications of Artificial Intelligence 23 (2010) 1314–1326.
- P. Fattahi, M. Saidi Mehrabad, F. Jolai. Mathematical modeling and heuristic approaches to flexible job shop scheduling problems. Journal of Intelligent Manufacturing (2007) 18:331–342.
- P. Fattahi , A. Fallahi .Dynamic scheduling in flexible job shop systems by considering simultaneously efficiency and stability. CIRP Journal of Manufacturing Science and Technology 2 (2010) 114–123
- P. Brandimarte. Routing and scheduling in a flexible job shop by tabu search. Annals of Operations Research 41(1993) 157-183
- S.Wang, L. Xi, B. Zhou. FBS-enhanced agent-based dynamic scheduling in FMS. Engineering Applications of Artificial Intelligence 21 (2008) 644–657
- M. Saidi-Mehrabad, P. Fattahi. Flexible job shop scheduling with tabu search algorithms. International Journal of Advanced Manufacturing Technology (2007) 32: 563–570.
- L. De Giovanni, F. Pezzella. An Improved Genetic Algorithm for the Distributed and Flexible Job-shop Scheduling problem. European Journal of Operational Research 200 (2010) 395–408.
- V. Prabhu. Stable Fault Adaptation in Distributed Control of Heterarchical Manufacturing Job Shops. IEEE Transactions on Robotics and Automation, Vol. 19, No. 1, (2003)
- M. Hussain. A Genetic Algorithm for Job Shop Scheduling Problems With Alternate Routing. Proceedings IEEE International Conference on Systems, Man, and Cybernetics, (1998) 3: 2225 - 2230

Thank you!

Any insights?
Any questions?

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