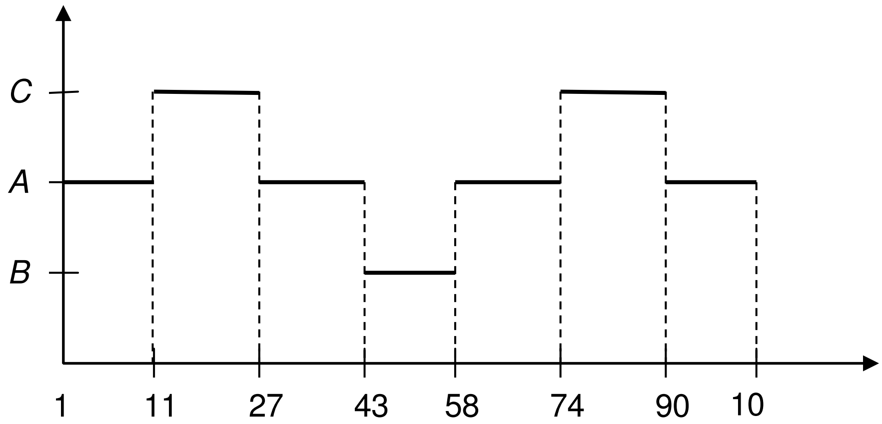
Test cases design

Apart from the defined data sets, additional examples were added from the literature (supplied through authors' web sites), if available for a particular environment.

Distributions of random variables

In the process of defining the test cases, it is necessary to use the generators of pseudorandom numbers that serve as the basis for job duration, arrival time etc. It is necessary to choose the probabilistic distribution that the generated random variables will follow. The sets used for learning use the uniform distribution generator obtained by a built-in MS Visual Studio generator. For the purposes of evaluation sets, we combined three distributions: uniform, normal (Gaussian) distribution and a quasi-bimodal distribution (similar to [Gre 01]). When composing an evaluatin set the distributions have been used in the following proportions: 20% of random values follow a uniform, 50% normal and 30% quasi-bimodal distribution. Probability function for a quasi-bimodal distribution is defined as in Figure 1 with the values of constants $B = 0.004651$, $A = 2B$ i $C = 3B$ (random variables values are set in the interval [1, 100]).



Slika 1. A probabilistic function of a quasi-bimodal distribution

Best solution selection

When choosing the best solution in all experiments, the best solutions from individual experiments were evaluated using a set of evaluation test examples, i.e. on a set that was not available during the learning process.

Another selection measure was the number of test cases in which the algorithm achieved a result that is either not worse than the results of any observed algorithm or is the best result found. This measure can be called and *the dominance percentage*. Dominance percentage may contribute to the choice of an algorithm if the observed algorithms differ only sloghtly in terms of total criteria value.

1. Single machine environment

Test cases for static environment

Test examples for static environments are defined by the following elements: job durations, job weights and job due date. The duration of each job can take on integer values in the interval from 1 to 100, a weight from 0.01 to 1 in increments of 0.01. Each test example is defined by two additional parameters by which the due dates are calculated. Parameter T is the due date tightness and parameter R is due date range [Lee 97], which both assume values in the interval $[0,1]$. For each test case, the due dates are defined with the uniform distribution within the interval

$$d_j \in \left[\sum_{j=1}^{n} p_j \left(1 - T - R/2\right), \sum_{j=1}^{n} p_j \left(1 - T + R/2\right) \right], \tag{0.1}$$

where n represents the number of jobs in the test case, with the restriction that the resulting value can not be less than zero.

Number of jobs in this environment takes on values of 12, 25, 50 and 100, and the parameters T and R assume values of 0.2, 0.4, 0.6, 0.8 and 1 in different combinations. In addition, from various sources [Bea 90] was obtained 375 additional test cases that are used only for evaluation.

Test cases for dynamic environment

Ispitni primjeri definirani su na sličan način kao i za statičku okolinu: pojedini primjer opisan je različitim vrijednostima parametara T i R, a područja dopuštenih vrijednosti jednaka su onima za statičku okolinu. Razlika u odnosu na prethodnu okolinu je uvođenje vremena pripravnosti poslova i različito računanje željenog vremena završetka. Za svaki ispitni primjer prvo su određena trajanja poslova te je izračunato ukupno trajanje svih poslova. Vremena pripravnosti generirana su jednolikom raspodjelom u intervalu

A single test case in a dynamic environment is described with different values of the parameters T and R with the same allowed values as in static environment. The difference compared to the previous environment is the introduction of ready time of jobs and different due date time. Ready times are generated with the uniform distribution in the interval

$$r_j \in \left[0, \frac{1}{2} \sum_{i=1}^{n} p_i \right]. \tag{0.2}$$

Due dates are generated in the following interval:

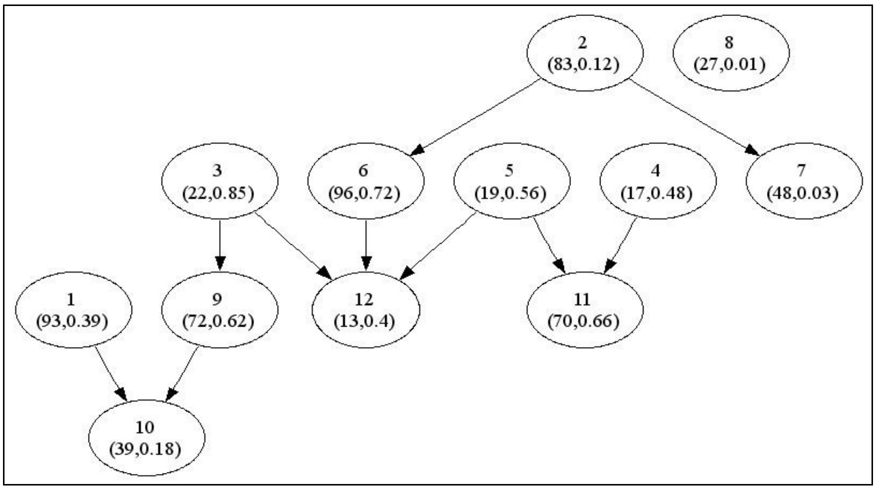
$$d_j \in \left[r_j + \left(\sum_{j=1}^{n} p_j - r_j \right) \cdot \left(1 - T - R/2\right), r_j + \left(\sum_{j=1}^{n} p_j - r_j \right) \cdot \left(1 - T + R/2\right) \right]. \tag{0.3}$$

Test cases with precedence constraints

Precedence constraints are designed in the most general form (which do not take the form of chains or single trees, etc.), which is the hardest variant of the problem. When creating constraints the following parameters are used:

- average ratio of jobs that will have precedessors is 80%,
- ratio of jobs with no predecessors is no less than 20%,
- largest number of immediate predecessors is 3,
- largest number of immediate successors is 4.

Experiments were also performed with different values, but the difference in terms of efficiency in these cases is not significant. Constraints are presented in the form of graphs, which are for all the test cases written in a format suitable for use in test scheduling rules. An example of dependency graph for a test instance with 12 jobs is shown in Figure 2. In this example, each node in the graph shows the number of the job and in parenthesis the duration of the job and its weight.



Slika 2. Dependence graph for a set of 12 jobs

Test cases with setup times

A duration is defined for each possible combination of previous and current job, which for a single test case makes a matrix of size $n \times n$. In some situations it can be assumed that the setup time between the two jobs is independent of their order, i.e. the matrix is symmetrical, but here we considered a general case.

The amount of data that would be required to store the duration of the setup for each test example is inappropriately large (eg, for 300 examples, with an average of 50 jobs, it would require 50 x 50 x 600 different values). Therefore, for each test example setup times are generated during the simulation, but using predefined random generator seed values for test cases so that they always return the same value (for comparison of different methods). Setup time is determined with uniform distribution using the additional parameter η which represents the ratio of the average duration of the setup and the average duration of the jobs. The value of this parameter is set to 0.5 in learning test cases and 0.5 and 1 in evaluation test cases.

2. Parallel uniform machines environment

Number of jobs in the test examples for learning can be 12, 25, 50 and 100, and in the evaluation 25, 50 and 100. Nominal values job durations are obtained as an integer value ranging from 1 to 100. For each test instance the number of machines is also defined, which for learning cases takes values of 3, 6 and 10, and in evaluation cases of 3, 6, 10, 15 and 20. In addition to the nominal job duration, it is necessary to define the speed s_i for each machine. Job j duration on machine i is then:

$$p_{ij} = p_j / s_i \,. \tag{0.4}$$

Speed of machines are determined using the random variable spd that for each machine takes its values in the interval $[0.1,1]$ in increments of 0.01 with uniform distribution. Machine speed is then defined as:

$$s_i = \frac{1}{spd} \tag{0.5}$$

Speeds defined in this way assume values from 1 to 10, but with a larger grouping at smaller values. Based on the speed of machines it is possible to define the *effective number of machines* $\hat{m}$ as the sum of all their speeds:

$$\hat{m} = \sum_{i=1}^{m} s_i \,, \tag{0.6}$$

where m is number of machines in a given test case. With the help of the effective number of machines we define the expected total duration of jobs $\hat{p}$ as

$$\hat{p} = \frac{1}{\hat{m}} \sum_{j=1}^{n} p_j \tag{0.7}$$

Ready times are generated with uniform distribution in the interval

$$r_j \in \left[0, \frac{\hat{p}}{2} \right] \tag{0.8}$$

In static environment (ready times are zero) the due dates are defined in the interval

$$d_j \in \left[\hat{p}\left(1-T-R/2\right), \hat{p}\left(1-T+R/2\right) \right], \tag{0.9}$$

whereas in dynamic environment in the interval

$$d_j \in \left[r_j + \left(\hat{p}-r_j\right)\cdot\left(1-T-R/2\right), r_j + \left(\hat{p}-r_j\right)\cdot\left(1-T+R/2\right) \right]. \tag{0.10}$$

Setup times (if included) are defined in the same way as for the single machine and do not depend on machine speed.

3. Parallel unrelated machines environment

In this environment the following holds:

- for each job its duration on each machine is defined (p_{ij}), a total of $n \times m$ values for each test case, where n is the number of jobs and m the number of machines;
- the expected total duration of jobs $\hat{p}$ is defined as

$$\hat{p} = \frac{\sum_{j=1}^{n} \sum_{i=1}^{m} p_{ij}}{m^2} \,. \tag{0.11}$$

Using the expected total duration and the parameters T and R, ready times are generated by the expression (0.8), and the due dates with (0.10). The objective function is formed in the same way as for uniform parallel machines with mean duration of the jobs expressed as $\bar{p} = \hat{p}/n$.

4. Job shop environment

In this environment for each job the duration of each operation and their order is defined. The duration of individual operations is generated in a manner equal to other environments. Order of operations is obtained by initially defining a series of ordinal numbers of machines, in order of size. Then the ordinal number of each element is replaced with another randomly selected element, until a series of operations for each job is generated. The expected total job duration for each test instance is defined as:

$$\hat{p} = \frac{1}{m} \sum_{j=1}^{n} \sum_{i=1}^{m} p_{ij} , \qquad (0.12)$$

where n is number of jobs and m number of machines in a given case. Due dates are defined with expressions (0.9) and (0.10).

The test cases are divided into a set of 160 training examples and a set of 320 evaluation examples. Additional 80 examples are used from [Tai 03] where the number of jobs ranges from 15 to 100 and number of machines is 15 or 20. All test cases are defined as a static environment in which all the jobs are ready since the beginning of the system execution.

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