

User manual of 'PLATE' : a decision support system for resource-constrained project scheduling problems

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prof.dr. H.G. Sol

**User manual of 'PLATE':
A DECISION SUPPORT SYSTEM
FOR RESOURCE-CONSTRAINED
PROJECT SCHEDULING PROBLEMS**

by

L. v.d. Bent
R. v. Dommelen
A. Jansen
L. Klieb
G. Wolf

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EINDHOVEN UNIVERSITY OF TECHNOLOGY
F. du Buisson
Department of Mathematics and Computing Science
P.O. Box 513
5600 MB EINDHOVEN

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L. v.d. Bent
Eindhoven University of Technology
Faculty of Mathematics and Computing Science
P.O. Box 513, 5600 MB Eindhoven, the Netherlands

R. v. Dommelen
Eindhoven University of Technology
Faculty of Mathematics and Computing Science
P.O. Box 513, 5600 MB Eindhoven, the Netherlands

A. Jansen
Eindhoven University of Technology
Faculty of Mathematics and Computing Science
P.O. Box 513, 5600 MB Eindhoven, the Netherlands

L. Klieb
Eindhoven University of Technology
Faculty of Mathematics and Computing Science
P.O. Box 513, 5600 MB Eindhoven, the Netherlands

G. Wolf
Eindhoven University of Technology
Faculty of Mathematics and Computing Science
P.O. Box 513, 5600 MB Eindhoven, the Netherlands

**User manual of "PLATE":
A Decision Support System for
Resource-Constrained Project Scheduling Problems**

*Department of Mathematics and Computing Science,
Eindhoven University of Technology
P.O. Box 513, 5600 MB Eindhoven, The Netherlands.*

(date: 25-01-1990)

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Introduction

1. Introduction

1.1. General remarks

In the framework of an exercise in Resource-Constrained Project Scheduling the Section Information Systems of the Department of Mathematics and Computer Science at the T.U.E. has developed a prototype D.S.S. for the problem situation that has been described in [1]. See also [3] for a short formal summary of the problem. In [3] are the main components of our system discussed.

This User Manual gives support in using the D.S.S. Our system consists of several parts, which are described in different chapters:

- A manual planner, to inspect a schedule on-screen, to assign tasks manually to a schedule, to delete tasks from the schedule, etc. (Chapter 2)
- An automatic planner, that attempts to generate good schedules automatically. (Chapter 3)
- A shell program to run the manual planner and the automatic planner under a common 'umbrella'. (Chapter 4)
- Some utilities, among which a compiler to transform the ASCII text files that define problem instances and schedules into database files which can be used by our system. Each problem has its own 'home' directory in which the database- and schedule files reside. (Chapter 5)

In appendix 1 we will give the ASCII-specification of our most important test case. Appendix 2 contains the ASCII-specification of a feasible schedule for this case.

1.2. About this manual

Some conventions define commands, instruction formats and terms in this manual:

- Words between **quotes** "" are keywords and must be entered as shown but without the quotes. You can enter either uppercase or lowercase characters.
- Items in *italics* must be supplied by yourself.
- Items between **hooked brackets** <> are keys from your keyboard.
- When an item is placed between **square brackets** [] it is optional.

1.3. Installing the system

To run "PLATE" and its utilities the following minimum configuration is required on your computer:

- IBM XT/AT compatible + colour display (no graphics card required: the syst0x works completely in text mode).
- 640 KB intern memory.

Introduction

- MS-DOS release 3.30 or higher.
- A (preferably fast) hard disk with 'enough' space (depending on the size of the problem-instances).

The FILES variable in your system configuration file (config.sys) has to be set to 50 or more.

We suggest to have one special system directory for "PLATE" which contains the following complete set of system files:

- PLATE.EXE The shell program
- HA.EXE The manual planner
- AUTORCPS.EXE The automatic planner
- AUTORCPS.OVR Overlay file for the automatic planner
- COMPILE.EXE The problem compiler
- CONFORM.EXE The syntax checker
- AHED.COM The Ascii-editor
- AHED.DOC The documentation file of Ahed

When running a "PLATE" program, one should always have the directory containing these files as current directory.

For every problem-instance a subdirectory should be created, to contain the problem-instance file and the corresponding schedule(s).

The batch program Plateinst can be used to install the system. You can run this program by typing:

```
"PLATEINST" source-directory target-directory <Enter>.
```

The *source- and target directory* should be specified with their whole pathnames. The *source directory* should contain the system files mentioned above. The *target directory* is the directory where the new system will be installed, this should be a new or an empty subdirectory.

Manual Planning

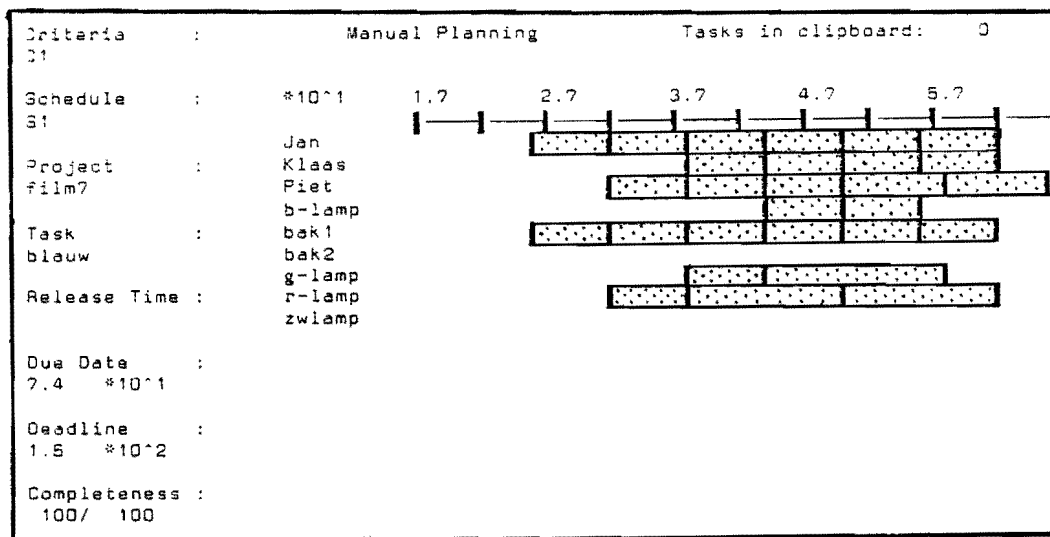
2. Manual Planning

2.1. Starting the Manual Planner

The Manual Planner can be run from the shell (see chapter 4).

2.2. The Screen

When you are in the Manual Planning Mode your screen will look like this:



When you take a close look at the screen you will see that it consists of four parts.

- First of all there is the **Planning window** on the right side below of the screen. This Planning Window contains a Gantt chart representation of a part of the actual schedule. On the left border there are the different resources and on the upper border is the time-axis. The scale of the time-axis is displayed in the left upper corner of this Planning Window. Inside the Planning Window you can recognize the state of a resource during some time interval by colours:
 - Black The resource is not available on the interval and there is no task planned on the interval using this resource.
 - Gray The resource is available on the whole interval and there is no task planned on the interval using this resource.
 - Green The resource is available on the interval and there is one task planned on the (whole) interval using this resource. The task has no conflicts w.r.t. the release times, deadlines and precedence constraints.

Manual Planning

Also **constraint violations** are made visible by colours:

Yellow	The resource is available on the interval and there is one task planned on the (whole) interval using this resource. The task has conflicts w.r.t. the release times or deadlines.
Blue	The resource is not available on the interval and there is one task planned on the whole interval using this resource.
Red	The resource is available on the interval and there is one task planned on the (whole) interval using this resource. The task has conflicts w.r.t the precedence.

A hatched colour means that the interval contains more than one piece of information (not all information can be displayed). The colour indicates only one of the states of the interval with the following priority blue, yellow, red, green, grey. Often **zooming (out)** can be used to separate the information (by stretching the interval). Only when a certain interval always contains more than one piece of information (e.g. when 2 tasks use the same resource and are partially planned in parallel), zooming doesn't help.

The starting time of a task is represented by a black dash. The Planning Window is not graphical. Its smallest unit is a column. More than one task may be scheduled in the interval of a column.

- The **Status part** is on the left of the Planning Window. It contains all information about the active schedule such as the criterion name, the schedule name and the name of the task and project where the cursor is pointing at in the Planning Window (the active task). In this Status part the deadline, the release time, the due date and also an indicator of the completeness of the task are given (number of planned tasks / total number of tasks).
- The **Clipboard** is above the Planning Window. You can use it as a temporary store for tasks which are already assigned to a resource set but which you want to move to another time slot. The list of these tasks will be empty when you enter the Manual Planning Mode.
- The last line of the screen gives you **help** information and may contain **error messages**.

2.3. Planning a new task

As soon as you are in the Manual Planning Mode you are able to allocate a task which is not already scheduled, and place it in the current schedule. You can choose two different ways to allocate a task. The first way (using <F3>) is to choose respectively the project, the task and finally the resource set. The second way (using <F4>) selects first the resource set, then project and task.

After this selection you will be able to choose available time slots (if there are any). By pressing <↑> or <↓> you can select any of the possible intervals. With <←> and <→> you are able to determine the exact position of the task within the interval: at the beginning or at the end; by entering numbers arbitrary starting times may be specified. You can cancel the operation by pressing <Esc>.

When there are no available time slots or when planning in a certain timeslot introduces conflicts, planning is yet possible by pressing <ALT>+<F1> and entering a starting time.

2.4. Shifting a task in the schedule

When you want to shift a task in the horizontal direction first put the task in the Clipboard by placing the cursor on the relevant task and then press <F5>. Then move the cursor to the new position and press <Enter>. If the task cannot be placed in that position (because there is no space),

Manual Planning

the task stays in the clipboard. You can fill the clipboard with all the tasks which are already scheduled. To scroll through the Clipboard press the <+> and <-> keys. The (only) visible item in the clipboard is the active one and will be placed in the schedule after pressing <Enter>. To move a task in vertical position (change the resourceset) you have to remove the task from the schedule by pressing and allocate the task again (<F3> or <F4>). Tasks which are on the Clipboard when leaving the Manual Planning Mode will be considered as removed.

2.5. Keys you can use in the planning board

The next functions are available :

Cursor movement functions :

- <↑> - Move cursor up
- <↓> - Move cursor down
- <←> - Move cursor left
- <→> - Move cursor right

Scroll functions :

- <PgUp> - Scroll Planning Window up.
- <PgDn> - Scroll Planning Window down.
- <HOME> - Scroll Planning Window left.
- <END> - Scroll Planning Window right.

Scheduling functions :

- <F3> - Select respectively project, task and resourceset to schedule.
- <F4> - Select respectively resourceset, project and task to schedule.
- - Remove active task from schedule.
- <F8> - Automatic planning.

Zoom functions :

- <F9> - Unzoom Planning Window.
- <F10> - Zoom Planning Window.

Display functions :

- <F2> - Show problem file.
- <F7> - Show criteria.

Miscellaneous :

- <Esc> - Quit the Manual Planner (with or without saving the updates of the last session).

Clipboard functions :

- <F6> - Remove the active task from the Clipboard.
- <+>, <-> - Scroll Clipboard.
- <F5> - Place the active task in the Clipboard.
- <Enter> - Place the task from the clipboard to the cursor position on the Planning Window.

3. Automatic Planning

3.1. Starting the automatic planner

The automatic planner can be started from the shell (see chapter 4).

3.2. Short description of the automatic planner's operation

For a description of the approximation method used, we refer to [3]. Here, it suffices to say that our automatic scheduler operates in 4 (sequential) phases:

phase	Name	Objective
1	resource scheduler	Determine for each task a resourceset with which it will be processed.
2	segment scheduler	Place each task in one of the segments during which its allocated resourceset is available.
3	sequence scheduler	Determine a processing order for each pair of tasks with non-disjunct resourcesets (they can not be processed in parallel).
4	time scheduler	Determine the starting- and completion times for the tasks (using the previous allocations).

For each of the phases 1, 2 and 3 we have implemented one scheduler. These 3 schedulers all use a so-called Greedy search algorithm with evaluation functions which assign values to (partial) filled schedules. These values are used to distinguish between schedules. The functions have weights (changeable by the user). The importance of a specific function (and thus its weight) depends on the problem to be scheduled.

For phase 4 we have made 2 implementations:

- One which generates a left or right justified schedule. This is a very fast scheduler which uses almost no extra memory.
- One which uses L.P. This a very time- and memory consuming approach which generates better time schedules than the previous one.

Almost always one should use the simple method, as time-optimal allocation will be influenced much more by the first 3 phases than the last one (most of the time, that is). L.P. is only useful in those special situations where the first 3 phases don't have to do much scheduling, and the optimality function has components where both earliness and tardiness play a role.

3.3. The options

After starting the automatic planner (either from the shell or the MS-DOS command line) and reading some data from the database into main memory (depending on the size of the problem, this takes a few seconds), the main menu appears. The following options are available:

1. Help
2. Edit parameters
3. Run scheduler
4. rUn scheduler using L.P.
5. Clear conflicts
6. cLear schedule
7. Manual planning

Menu options can be selected by pressing the key corresponding to the highlighted letter, or moving

Automatic planning

the bar to the option of one's choice and pressing <ENTER>. In the following paragraphs we will explain the 6 options.

3.3.1. Help

Selecting the Help-option opens a status-window which gives some useful information about the system. It looks something like this:

```
Help & Information service
This heuristic for Resource Constrained Project Scheduling (RCPS)
operates in 4 main phases:
 1. Resource scheduling (assigns a resourceset to each task).
 2. Segment scheduling (assigns to each task one of the timesegments in
    which the resourceset for that task is available).
 3. Task sequencing (assigns an order to each pair of tasks with conflicting
    resourcesets).
 4. Time scheduling (assigns to each task a suitable starting time).

Current heap state:
Initial available memory           : 142 Kb.
Current available memory           : 116 Kb.
- Primary problem data             : 22 Kb.
- Database, windows, precedence data etc.: 3 Kb.
Largest available block            : 116 Kb.
Size of freelist (fragmentation)   : 0 element(s).

Tasks : 100  Errors : 1  % Done : 100.00
Press a key to continue.
```

3.3.2. Edit parameters

This option allows updating of parameters for the 5 schedulers in the system. After selecting this menu option, a submenu appears where the scheduler can be selected for which one wants to change the parameters:

1. Resource scheduler
2. Segment scheduler
3. sEquence scheduler
4. Fast time scheduler
5. L.P. time scheduler

The editing of parameters works via so-called forms. Moving between entries in a form works via the standard cursor keys and the <RETURN>-key.

Automatic planning

3.3.2.1. Resource scheduler parameters

Layout of the form:

```
Resourcescheduler/Parameters
-----
Search data          Evaluator data
-----
Max. nodes: 25      Max. occupation resources : 0.900
Max. depth: 1       Max. occupation resourcesets : 0.550
                   Max. local tasks : 6

Evaluator weights    Result files
-----
Feasibility          : 1000000000  Search report
Freedom              : 3.000       Generate: No
Due date distance    : 0.000       Name : ressched.ext
Resource occupation  :
Smooth exceedings    : 40.000       Result report
Total exceedings     : 2000.000     Generate: Yes
Resource set occupation
Smooth exceeding     : 20.000       Name : ressched.res
Total exceedings     : 1500.000
```

3.3.2.2. Segment scheduler parameters

Layout of the form:

```
Segmentscheduler/Parameters
-----
Search data          Evaluator data
-----
Max. nodes: 25      Max. occup. resourcesegments : 1.000
Max. depth: 1       Max. occup. resourceset segments: 1.000
                   Max. local tasks : 6

Evaluator weights    Result files
-----
Feasibility          : 1000000000  Search report
Freedom local tasks  : 2.000       Generate: No
Freedom precedences  : 2.000       Name : segsched.ext
Due date distance    : 1.000       Result report
Resource(segment) occupation
Smooth exceedings    : 100.000     Generate: Yes
Total exceedings     : 20000.000   Name : segsched.res
Resource set(segment) occupation
Smooth exceedings    : 20.000
Total exceedings     : 20000.000
```

3.3.2.3. Sequence scheduler parameters

No explanation is necessary.

3.3.2.4. Fast time scheduler

No explanation is necessary.

Automatic planning

3.3.2.5. L.P.-time scheduler

Only the first parameter needs some explanation. L.P. time scheduling handles the tasks in a number of batches. In every batch for a certain number of tasks, say n , starting- and completion times will be determined. When f ($0 < f \leq 1$) is the minimal fraction of running tasks, for at least $f \cdot n$ tasks the allocations will be kept after determination. The time-allocations for the other tasks will be removed when expected bad. These tasks will be processed in a next batch. The lower f , the better the results but the slower the scheduler (more batches are needed).

3.3.3. Run scheduler

This option calls the automatic scheduler. It extends the actual schedule to a complete schedule by sequentially walking through the 4 phases as mentioned. The progress of the scheduler can continuously be monitored on screen. When scheduling is complete, the system reports the number of errors in the resulting schedule (see screen dump below for an example). The reportfiles (the paths and names of which are set in the parameter-forms) contain useful information and a summary of the scheduling decisions taken.

Note that this option uses the fast time scheduler to generate a left- or right justified time schedule (depending on the parameter setting).

```
Help
Edit parameters
Run scheduler

Scheduling done
Total number of tasks = 100      Number of conflicts = 1
Resourcesetallocations = 0      Timeallocations = 0
Total schedulingtime (h:m:s):    0:0:14
Press any key to continue.
```

3.3.4. Run scheduler using L.P.

Analogous to 3.2.3., but now L.P. is used for time-scheduling (see paragraph 3.2).

3.3.5. Clear conflicts

This option scans the tasks for errors, and removes allocations for wrongly planned tasks. The process works non-deterministic. For example: let 3 tasks t , u and v be planned as follows, each using the same resourceset:



Here, we can consider task v in error or both tasks t and u in error. Depending on the order in which the tasks will be scanned by the conflict remover, only the allocations for task v will be removed or the allocations for both tasks t and u will be removed.

Automatic planning

3.3.6. Clear schedule

This option clears the internal schedule (resulting in an empty internal schedule).

3.3.7. Manual planning

This option returns to the Manual Planning Mode.

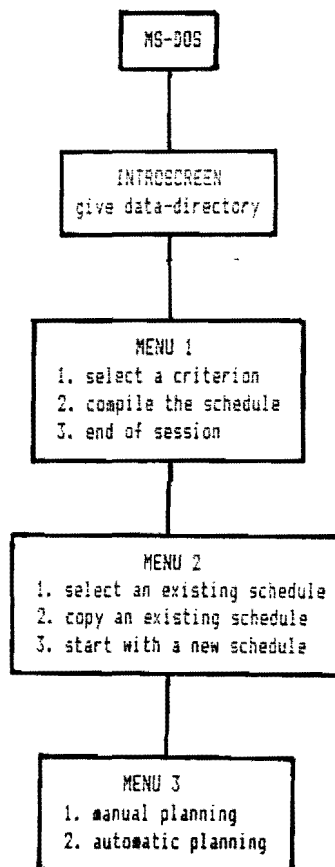
4. The Shell

4.1. Starting the Shell System

Make sure you are in the directory with the system files and type "PLATE" [*data-directory*] <ENTER>; *data-directory* is the (optional) path to the directory of the problem-instance which is to be used in this session. When you do not specify the data-directory, the program will prompt you for its name.

4.2. Structure of the Shell System

The global structure of the shell looks as follows:



From the MS-DOS prompt the introsreen will be displayed where you have to enter the data-directory only when you didn't specify it on the command line. Then you will see the first menu with three items: 'End of Session', 'Compile the Schedules to an ASCII-file' and 'Select a criterion' for making a schedule.

4.3. Compile schedules to an ASCII-file

With this menu option you are able to generate an ASCII-format (text)file of all schedules belonging to the problem-instance.

The Shell

This file gets the name 'schedule.xxx', where xxx stands for the first free number greater than 0. So the first time the program will give the ASCII-file the name 'schedule.001', the second time 'schedule.002' etc. After completing this task, menu1 will re-appear.

4.4. Selecting a criterion

By choosing the item 'Select a criterion' in the first menu, the program will show you all the existing criteria. Use <↓> and <↑> to choose the criterion. When there are more items than shown on the screen, <PgUp> and <PgDn> can be used to select previous/next menu pages. Press <Enter> to select the criterion that is coloured, after you will go directly to menu2 where you are able to select a schedule. Press <Esc> to cancel and return to menu1

4.5. Selecting a schedule

After you have selected a criterion you have to specify with which schedule you want to work. This can be an existing schedule which you want to modify, an existing schedule which you want to modify under a new name or a completely new empty schedule. Choose the item you want by using <↑> and <↓> and press <Enter>. You may select an existing schedule name and/or specify a new schedule name. Press <Esc> when you want to return to the previous menu; otherwise you will enter menu3.

4.6. Selecting the planning mode

Here we arrived at the main part of the program: 'Planning'. You can choose between two planning modes : manual or automatic planning. Both planning modes are described in previous chapters (see 2 and 3). <Esc> can be used to return to the previous menu.

4.7. Display the problem-instance file

By pressing <F2> you may inspect the problem-instance file during the planning session. The next functions are available in this viewer:

Scroll functions :

- <↑> - Scroll screen one row up.
- <↓> - Scroll screen one row down.
- <Enter> - Scroll screen one row down.
- <PgUp> - Scroll screen up.
- <PgDn> - Scroll screen down.
- <Home> - Go to the begin of the file.
- <End> - Go to the end of the file.

Search functions :

- </> *string* <Enter> - Search forward to first appearance of *string*.
- <?> *string* <Enter> - Search backward to first appearance of *string*.
- </> <Enter> - Repeat last search forward.
- <?> <Enter> - Repeat last search backward.

Miscellaneous :

- <Esc> - Quit the viewer mode.

Utilities

5. Utilities

5.1. The problem-instance compiler

To work on a problem in PLATE you first have to generate database-files from the ASCII specification. This is done by the utility **Compile.exe**. You can run the compiler by typing:

```
"COMPILE" [directory] <Enter>.
```

The directory is optional in this command. Compile will make the specified directory current, so you don't have to type the whole pathname when entering the names of the ASCII-files to be compiled.

Upon entry, the program asks for the (ASCII) problem file and the (ASCII) schedule file. When you don't want to compile an item simply give <Enter> on the relevant question. The system will ask you now for a directory to store the database files which will be generated by the compiler. Type "." (+<Enter>) if you want this database-directory to be the current directory. When all files are compiled correctly the program will end with the notice "Correct Termination".

5.2. The syntax checker

Before running the compiler one should use the utility **Conform.exe** to check whether the syntax of the problem definition is correct. The usage of this program is as follows:

```
"CONFORM" problem-file schedule-file [message-file] <Enter>.
```

Specification of the *message-file* is optional. The default name for this file is 'errors.txt'. The file will contain all errors and warnings found during parsing.

The *problem-file* is the ASCII problem-instance specification to be parsed. The *schedule-file* is an ASCII schedule specification to be parsed.

5.3. The Ascii-editor "AHED"

The AHED Ascii-editor is a simple editor (like Wordstar) which can be used to edit a problem-instance file.

Type AHED to start the editor. When you want help use <F1>. For more information look in the AHED.DOC file.

6. Literature

- [1] J.M. Anthonisse, K.M. van Hee, J.K.Lenstra. "Resource-Constrained Project Scheduling: an International Exercise in DSS Development", *Decision Support Systems* 4 (1988).
- [2] AHED, The Ad Hoc Editor. M.A. Covington, Advanced Computational Methods Center, University of Georgia, Athens, GA 30602.
- [3] A. Jansen, L. Klieb, C. Noorlander, G. Wolf. "PLATE: A Decision Support System for Resource-Constrained Project Scheduling Problems", Eindhoven University of Technology, Eindhoven (1990).

Appendix 1. Example of a case: A photo development and printing company.

*projects							
zwfotos	,	26,	474,	550;			
foto	,	26,	450,	500;			
film1	,	200,	470,	600;			
film2	,	,	,	;			
film3	,	0,	274,	400;			
film4	,	0,	274,	400;			
film5	,	0,	,	;			
film6	,	,	350,	600;			
film7	,	26,	74,	160;			
*							
*tasks							
film1	,	ontwikl	,	ontwikl	,	72,	;
film1	,	rood	,	afdr-r	,	96,	;
film1	,	groen	,	afdr-g	,	96,	;
film1	,	blauw	,	afdr-b	,	96,	;
film2	,	ontwikl	,	ontwikl	,	72,	0,
film2	,	rood	,	afdr-r	,	96,	;
film2	,	groen	,	afdr-g	,	96,	;
film2	,	blauw	,	afdr-b	,	96,	174,
film3	,	ontwikl	,	ontwikl	,	72,	200,
film3	,	rood	,	afdr-r	,	96,	;
film3	,	groen	,	afdr-g	,	96,	;
film3	,	blauw	,	afdr-b	,	96,	;
film4	,	ontwikl	,	ontwikl	,	72,	;
film4	,	rood	,	afdr-r	,	96,	;
film4	,	groen	,	afdr-g	,	96,	;
film4	,	blauw	,	afdr-b	,	96,	;
film5	,	ontwikl	,	ontwikl	,	72,	;
film5	,	rood	,	afdr-r	,	96,	;
film5	,	groen	,	afdr-g	,	96,	;
film5	,	blauw	,	afdr-b	,	96,	174,
film6	,	ontwikl	,	ontwikl	,	72,	200,
film6	,	rood	,	afdr-r	,	96,	;
film6	,	groen	,	afdr-g	,	96,	;
film6	,	blauw	,	afdr-b	,	96,	0,
film7	,	ontwikl	,	ontwikl	,	72,	350,
film7	,	rood	,	afdr-r	,	96,	;
film7	,	groen	,	afdr-g	,	96,	;
film7	,	blauw	,	afdr-b	,	96,	74,
zwfotos	,	ontw1	,	ontwikl	,	72,	0,
zwfotos	,	afdr1	,	afdruk	,	30,	134,
zwfotos	,	ontw2	,	ontwikl	,	72,	174,
zwfotos	,	afdr2	,	afdruk	,	30,	474,
zwfotos	,	ontw3	,	ontwikl	,	72,	0,
zwfotos	,	ontw4	,	ontwikl	,	72,	0,
zwfotos	,	ontw5	,	ontwikl	,	72,	200,
zwfotos	,	ontw6	,	ontwikl	,	72,	200,
zwfotos	,	ontw7	,	ontwikl	,	72,	0,
zwfotos	,	ontw8	,	ontwikl	,	72,	200,
zwfotos	,	ontw9	,	ontwikl	,	72,	200,
zwfotos	,	ontw10	,	ontwikl	,	72,	200,
zwfotos	,	ontw11	,	ontwikl	,	72,	200,
zwfotos	,	ontw12	,	ontwikl	,	72,	200,
zwfotos	,	ontw13	,	ontwikl	,	72,	200,
zwfotos	,	ontw14	,	ontwikl	,	72,	200,
zwfotos	,	ontw15	,	ontwikl	,	72,	200,
zwfotos	,	ontw16	,	ontwikl	,	72,	200,
zwfotos	,	ontw17	,	ontwikl	,	72,	200,
zwfotos	,	ontw18	,	ontwikl	,	72,	200,
zwfotos	,	ontw19	,	ontwikl	,	72,	200,
zwfotos	,	ontw20	,	ontwikl	,	72,	200,
zwfotos	,	afdr3	,	afdruk	,	30,	250,
zwfotos	,	afdr4	,	afdruk	,	30,	274,

zwfotos	,afdr5	,afdruk	,	30,	,	250,	,	;
zwfotos	,afdr6	,afdruk	,	30,	,	250,	,	;
zwfotos	,afdr7	,afdruk	,	30,	,	250,	,	;
zwfotos	,afdr8	,afdruk	,	30,	,	474,	,	;
zwfotos	,afdr9	,afdruk	,	30,	,	274,	,	;
zwfotos	,afdr10	,afdruk	,	30,	,	474,	,	;
zwfotos	,afdr11	,afdruk	,	30,	,	474,	,	;
zwfotos	,afdr12	,afdruk	,	30,	,	474,	,	;
zwfotos	,afdr13	,afdruk	,	30,	,	474,	,	;
zwfotos	,afdr14	,afdruk	,	30,	,	474,	,	;
zwfotos	,afdr15	,afdruk	,	30,	,	474,	,	;
zwfotos	,afdr16	,afdruk	,	30,	,	474,	,	;
zwfotos	,afdr17	,afdruk	,	30,	,	474,	,	;
zwfotos	,afdr18	,afdruk	,	30,	,	474,	,	;
zwfotos	,afdr19	,afdruk	,	30,	,	474,	,	;
zwfotos	,afdr20	,afdruk	,	30,	,	374,	,	;
foto	,ontw1	,ontwikl	,	72,	0,	,	,	foto1 ;
foto	,rood1	,afdr-r	,	72,	,	,	,	foto1 ;
foto	,groen1	,afdr-g	,	72,	,	,	,	foto1 ;
foto	,blauw1	,afdr-b	,	72,	,	74,	300,	foto1 ;
foto	,ontw2	,ontwikl	,	72,	0,	,	,	foto2 ;
foto	,rood2	,afdr-r	,	72,	,	,	,	foto2 ;
foto	,groen2	,afdr-g	,	72,	,	,	,	foto2 ;
foto	,blauw2	,afdr-b	,	72,	,	74,	300,	foto2 ;
foto	,ontw3	,ontwikl	,	72,	0,	,	,	foto3 ;
foto	,rood3	,afdr-r	,	72,	,	,	,	foto3 ;
foto	,groen3	,afdr-g	,	72,	,	,	,	foto3 ;
foto	,blauw3	,afdr-b	,	72,	,	74,	300,	foto3 ;
foto	,ontw4	,ontwikl	,	72,	200,	,	,	foto4 ;
foto	,rood4	,afdr-r	,	72,	,	,	,	foto4 ;
foto	,groen4	,afdr-g	,	72,	,	,	,	foto4 ;
foto	,blauw4	,afdr-b	,	72,	,	370,	,	foto4 ;
foto	,ontw5	,ontwikl	,	72,	200,	,	,	foto5 ;
foto	,rood5	,afdr-r	,	72,	,	,	,	foto5 ;
foto	,groen5	,afdr-g	,	72,	,	,	,	foto5 ;
foto	,blauw5	,afdr-b	,	72,	,	370,	,	foto5 ;
foto	,ontw6	,ontwikl	,	72,	0,	,	,	foto6 ;
foto	,rood6	,afdr-r	,	72,	,	,	,	foto6 ;
foto	,groen6	,afdr-g	,	72,	,	,	,	foto6 ;
foto	,blauw6	,afdr-b	,	72,	,	74,	300,	foto6 ;
foto	,ontw7	,ontwikl	,	72,	0,	,	,	foto7 ;
foto	,rood7	,afdr-r	,	72,	,	,	,	foto7 ;
foto	,groen7	,afdr-g	,	72,	,	,	,	foto7 ;
foto	,blauw7	,afdr-b	,	72,	,	74,	300,	foto7 ;
foto	,ontw8	,ontwikl	,	72,	200,	,	,	foto8 ;
foto	,rood8	,afdr-r	,	72,	,	,	,	foto8 ;
foto	,groen8	,afdr-g	,	72,	,	,	,	foto8 ;
foto	,blauw8	,afdr-b	,	72,	,	370,	,	foto8 ;

*

*precedence

zwfotos	,ontw1	,afdr1	,	,	,	,	,	;
zwfotos	,ontw2	,afdr2	,	,	,	,	,	;
zwfotos	,ontw3	,afdr3	,	,	,	,	,	;
zwfotos	,ontw4	,afdr4	,	,	,	,	,	;
zwfotos	,ontw5	,afdr5	,	,	,	,	,	;
zwfotos	,ontw6	,afdr6	,	,	,	,	,	;
zwfotos	,ontw7	,afdr7	,	,	,	,	,	;
zwfotos	,ontw8	,afdr8	,	,	,	,	,	;
zwfotos	,ontw9	,afdr9	,	,	,	,	,	;
zwfotos	,ontw10	,afdr10	,	,	,	,	,	;
zwfotos	,ontw11	,afdr11	,	,	,	,	,	;
zwfotos	,ontw12	,afdr12	,	,	,	,	,	;
zwfotos	,ontw13	,afdr13	,	,	,	,	,	;
zwfotos	,ontw14	,afdr14	,	,	,	,	,	;
zwfotos	,ontw15	,afdr15	,	,	,	,	,	;
zwfotos	,ontw16	,afdr16	,	,	,	,	,	;
zwfotos	,ontw17	,afdr17	,	,	,	,	,	;
zwfotos	,ontw18	,afdr18	,	,	,	,	,	;

zwlotos	,ontw19	,afdr19	,	,	;
zwlotos	,ontw20	,afdr20	,	,	;
film1	,ontwikl	,rood	,	,	;
film2	,ontwikl	,rood	,	,	;
film3	,ontwikl	,rood	,	,	;
film4	,ontwikl	,rood	,	,	;
film5	,ontwikl	,rood	,	,	;
film6	,ontwikl	,rood	,	,	;
film7	,ontwikl	,rood	,	,	;
film1	,rood	,groen	,	,	0;
film2	,rood	,groen	,	,	0;
film3	,rood	,groen	,	,	0;
film4	,rood	,groen	,	,	0;
film5	,rood	,groen	,	,	0;
film6	,rood	,groen	,	,	0;
film7	,rood	,groen	,	,	0;
film1	,groen	,blauw	,	,	8;
film2	,groen	,blauw	,	,	8;
film3	,groen	,blauw	,	,	8;
film4	,groen	,blauw	,	,	8;
film5	,groen	,blauw	,	,	8;
film6	,groen	,blauw	,	,	8;
film7	,groen	,blauw	,	,	8;
foto	,ontw1	,rood1	,	,	;
foto	,ontw1	,groen1	,	,	;
foto	,ontw1	,blauw1	,	,	;
foto	,rood1	,groen1	,	-18,	12;
foto	,groen1	,blauw1	,	-18,	12;
foto	,blauw1	,rood1	,	-18,	12;
foto	,ontw2	,rood2	,	,	;
foto	,ontw2	,groen2	,	,	;
foto	,ontw2	,blauw2	,	,	;
foto	,rood2	,groen2	,	-18,	12;
foto	,groen2	,blauw2	,	-18,	12;
foto	,blauw2	,rood2	,	-18,	12;
foto	,ontw3	,rood3	,	,	;
foto	,ontw3	,groen3	,	,	;
foto	,ontw3	,blauw3	,	,	;
foto	,rood3	,groen3	,	-18,	12;
foto	,groen3	,blauw3	,	-18,	12;
foto	,blauw3	,rood3	,	-18,	12;
foto	,ontw4	,rood4	,	,	;
foto	,ontw4	,groen4	,	,	;
foto	,ontw4	,blauw4	,	,	;
foto	,rood4	,groen4	,	-18,	12;
foto	,groen4	,blauw4	,	-18,	12;
foto	,blauw4	,rood4	,	-18,	12;
foto	,ontw5	,rood5	,	,	;
foto	,ontw5	,groen5	,	,	;
foto	,ontw5	,blauw5	,	,	;
foto	,rood5	,groen5	,	-18,	12;
foto	,groen5	,blauw5	,	-18,	12;
foto	,blauw5	,rood5	,	-18,	12;
foto	,ontw6	,rood6	,	,	;
foto	,ontw6	,groen6	,	,	;
foto	,ontw6	,blauw6	,	,	;
foto	,rood6	,groen6	,	-18,	12;
foto	,groen6	,blauw6	,	-18,	12;
foto	,blauw6	,rood6	,	-18,	12;
foto	,ontw7	,rood7	,	,	;
foto	,ontw7	,groen7	,	,	;
foto	,ontw7	,blauw7	,	,	;
foto	,rood7	,groen7	,	-18,	12;
foto	,groen7	,blauw7	,	-18,	12;
foto	,blauw7	,rood7	,	-18,	12;
foto	,ontw8	,rood8	,	,	;
foto	,ontw8	,groen8	,	,	;
foto	,ontw8	,blauw8	,	,	;

```

foto      ,rood8      ,groen8      ,      -18,      12;
foto      ,groen8     ,blauw8     ,      -18,      12;
foto      ,blauw8     ,rood8      ,      -18,      12;

```

*

*resources

```

bak1      ,          ,kamer1      ;
bak2      ,          ,kamer2      ;
zwlamp    ,lamp      ,zwkamer     ;
Jan       ,man       ,            ;
Piet      ,man       ,            ;
Klaas     ,man       ,            ;
r-lamp    ,lamp      ,kleurkamer;
g-lamp    ,lamp      ,kleurkamer;
b-lamp    ,lamp      ,kleurkamer;

```

*

*availabilities

```

Jan       ,      26,      74;
Jan       ,     126,     174;
Jan       ,     226,     274;
Jan       ,     326,     374;
Jan       ,     426,     474;
Jan       ,     526,     574;
Piet      ,      26,      74;
Piet      ,     126,     174;
Piet      ,     226,     274;
Piet      ,     326,     374;
Piet      ,     426,     474;
Klaas     ,     426,     474;
Klaas     ,     326,     374;
Klaas     ,     226,     274;
Klaas     ,     126,     174;
Klaas     ,      26,      74;
Klaas     ,     526,     574;
Klaas     ,     626,     674;
bak1      ,      0, 987654;
bak2      ,     100,     300;
zwlamp    ,      26,     574;
r-lamp    ,      0,     600;
g-lamp    ,      2,     600;
b-lamp    ,      1,     700;

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*

*resource sets

```

j-ontw1   ,Jan       ;
j-ontw1   ,bak1      ;
p-ontw1   ,Piet      ;
p-ontw1   ,bak1      ;
j-ontw2   ,Jan       ;
j-ontw2   ,bak2      ;
p-ontw2   ,Piet      ;
p-ontw2   ,bak2      ;
j-zw      ,Jan       ;
j-zw      ,zwlamp    ;
p-zw      ,Piet      ;
p-zw      ,zwlamp    ;
p-rood    ,Piet      ;
p-rood    ,r-lamp    ;
k-rood    ,Klaas     ;
k-rood    ,r-lamp    ;
p-groen   ,Piet      ;
p-groen   ,g-lamp    ;
k-groen   ,Klaas     ;
k-groen   ,g-lamp    ;
p-blauw   ,Piet      ;
p-blauw   ,b-lamp    ;
k-blauw   ,Klaas     ;
k-blauw   ,b-lamp    ;

```

*

*functions

```

ontwikl , j-ontw1 , 12;
ontwikl , p-ontw1 , 12;
ontwikl , j-ontw2 , 4;
ontwikl , p-ontw2 , 4;
afdruk , j-zw , 5;
afdruk , p-zw , 5;
afdr-r , p-rood , 12;
afdr-r , k-rood , 12;
afdr-g , p-groen , 12;
afdr-g , k-groen , 12;
afdr-b , p-blauw , 12;
afdr-b , k-blauw , 12;

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*

*task criteria

```

tw1 , film1 , blauw , 1, 10;
tw1 , film2 , blauw , , 10;
tw1 , film3 , blauw , , 20;
tw1 , film4 , blauw , 2, 20;
tw1 , film5 , blauw , 15, 15;
tw1 , film6 , blauw , , 10;
tw1 , film7 , blauw , 5, 6;
tw1 , zwfotos , afdr1 , , 7;
tw1 , zwfotos , afdr2 , , 6;
tw1 , zwfotos , afdr3 , 5, 5;
tw1 , zwfotos , afdr4 , , 8;
tw1 , zwfotos , afdr5 , , 12;
tw1 , zwfotos , afdr6 , 10, 10;
tw1 , zwfotos , afdr7 , , 8;
tw1 , zwfotos , afdr8 , , 10;
tw1 , zwfotos , afdr9 , , 10;
tw1 , zwfotos , afdr10 , , 12;
tw1 , zwfotos , afdr11 , 14, 14;
tw1 , zwfotos , afdr12 , , 10;
tw1 , zwfotos , afdr13 , , 8;
tw1 , zwfotos , afdr14 , , 8;
tw1 , zwfotos , afdr15 , , 8;
tw1 , zwfotos , afdr16 , 8, 8;
tw1 , zwfotos , afdr17 , , 8;
tw1 , zwfotos , afdr18 , , 8;
tw1 , zwfotos , afdr19 , , 8;
tw1 , zwfotos , afdr20 , , 8;
tw1 , foto , blauw1 , , 10;
tw1 , foto , blauw2 , , 10;
tw1 , foto , blauw3 , , 10;
tw1 , foto , blauw4 , , 10;
tw1 , foto , blauw5 , 10, 10;
tw1 , foto , blauw6 , , 10;
tw1 , foto , blauw7 , 10, 10;
tw1 , foto , blauw8 , , 10;
tw2 , film5 , blauw , , 20;
tw2 , film7 , blauw , , 20;
tw2 , zwfotos , afdr9 , , 20;
tw2 , foto , blauw7 , , 20;

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*

*project criteria

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pw1 , foto , , 10, 10;
pw1 , film1 , , 5, 5;
pw1 , film2 , , 5, 5;
pw1 , film3 , , 5, 5;
pw1 , film6 , , 5, 5;
pw1 , film7 , , 6, 6;
pw1 , zwfotos , , 12, 12;
pw2 , foto , , , 7;
pw2 , zwfotos , , , 10;
pw2 , film1 , , , 5;
pw2 , film4 , , , 4;
pw2 , film2 , , , 4;
pw2 , film3 , , , 4;

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pw2      ,film5      ,      ,      4;
pw2      ,film6      ,      ,      4;
pw2      ,film7      ,      ,      4;
*
*overall criteria
c1      ,pw1      ,      ,      ,      1,      ,      1;
c2      ,      ,tw1      ,      ,      1,      ,      1,      ;
c3      ,pw1      ,      ,      ,      1,      ,      1,      ;
c4      ,      ,tw1      ,      ,      ,      1,      ,      1;
c5      ,      ,tw2      ,      ,      1,      2,      1,      2;
c6      ,pw1      ,tw1      ,      ,      1,      2,      3,      4;
*
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Appendix 2. A feasible schedule for the photo development and printing company.

*schedules

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! day1
sl ,cl ,foto ,ontw7 ,j-ontw1 , 26, 32;
sl ,cl ,foto ,ontw2 ,j-ontw1 , 32, 38;
sl ,cl ,film7 ,ontwik1 ,j-ontw1 , 38, 44;
sl ,cl ,zwfotos ,ontw1 ,j-ontw1 , 44, 50;
sl ,cl ,foto ,ontw1 ,j-ontw1 , 50, 56;
sl ,cl ,film2 ,ontwik1 ,j-ontw1 , 56, 62;
sl ,cl ,foto ,ontw3 ,j-ontw1 , 62, 68;
sl ,cl ,foto ,rood7 ,p-rood , 32, 38;
sl ,cl ,foto ,groen7 ,p-groen , 38, 44;
sl ,cl ,foto ,blauw7 ,p-blauw , 44, 50;
sl ,cl ,film7 ,rood ,p-rood , 50, 58;
sl ,cl ,film7 ,groen ,p-groen , 58, 66;
sl ,cl ,film7 ,blauw ,p-blauw , 66, 74;
sl ,cl ,foto ,rood2 ,k-rood , 38, 44;
sl ,cl ,foto ,groen2 ,k-groen , 44, 50;
sl ,cl ,foto ,blauw2 ,k-blauw , 50, 56;
sl ,cl ,foto ,blauw1 ,k-blauw , 56, 62;
sl ,cl ,foto ,rood1 ,k-rood , 62, 68;
sl ,cl ,foto ,groen1 ,k-groen , 68, 74;
! day2
sl ,cl ,zwfotos ,ontw3 ,j-ontw1 , 126, 132;
sl ,cl ,foto ,ontw6 ,j-ontw1 , 132, 138;
sl ,cl ,film5 ,ontwik1 ,j-ontw1 , 138, 144;
sl ,cl ,zwfotos ,ontw7 ,j-ontw1 , 144, 150;
sl ,cl ,film4 ,ontwik1 ,j-ontw1 , 150, 156;
sl ,cl ,film3 ,ontwik1 ,j-ontw1 , 156, 162;
sl ,cl ,zwfotos ,ontw4 ,j-ontw1 , 162, 168;
sl ,cl ,zwfotos ,ontw2 ,j-ontw1 , 168, 174;
sl ,cl ,zwfotos ,afdr1 ,p-zw , 126, 132;
sl ,cl ,film2 ,rood ,p-rood , 132, 140;
sl ,cl ,film2 ,groen ,p-groen , 140, 148;
sl ,cl ,film2 ,blauw ,p-blauw , 148, 156;
sl ,cl ,foto ,rood6 ,p-rood , 156, 162;
sl ,cl ,foto ,groen6 ,p-groen , 162, 168;
sl ,cl ,foto ,blauw6 ,p-blauw , 168, 174;
sl ,cl ,foto ,rood3 ,k-rood , 126, 132;
sl ,cl ,foto ,groen3 ,k-groen , 132, 138;
sl ,cl ,foto ,blauw3 ,k-blauw , 138, 144;
sl ,cl ,film5 ,rood ,k-rood , 144, 152;
sl ,cl ,film5 ,groen ,k-groen , 152, 160;
sl ,cl ,film5 ,blauw ,k-blauw , 160, 168;
! day3
sl ,cl ,foto ,ontw5 ,j-ontw2 , 226, 244;
sl ,cl ,zwfotos ,ontw6 ,j-ontw1 , 244, 250;
sl ,cl ,zwfotos ,ontw12 ,j-ontw2 , 250, 268;
sl ,cl ,foto ,ontw8 ,j-ontw1 , 268, 274;
sl ,cl ,foto ,ontw4 ,p-ontw1 , 226, 232;
sl ,cl ,zwfotos ,ontw9 ,p-ontw1 , 232, 238;
sl ,cl ,zwfotos ,ontw5 ,p-ontw1 , 238, 244;
sl ,cl ,zwfotos ,afdr3 ,p-zw , 244, 250;
sl ,cl ,zwfotos ,afdr5 ,p-zw , 250, 256;
sl ,cl ,zwfotos ,afdr6 ,p-zw , 256, 262;
sl ,cl ,zwfotos ,ontw18 ,p-ontw1 , 262, 268;
sl ,cl ,zwfotos ,afdr7 ,p-zw , 268, 274;
sl ,cl ,film4 ,rood ,k-rood , 226, 234;
sl ,cl ,film4 ,groen ,k-groen , 234, 242;
sl ,cl ,film4 ,blauw ,k-blauw , 242, 250;
sl ,cl ,film3 ,rood ,k-rood , 250, 258;
sl ,cl ,film3 ,groen ,k-groen , 258, 266;
sl ,cl ,film3 ,blauw ,k-blauw , 266, 274;
! day4
sl ,cl ,zwfotos ,afdr9 ,j-zw , 326, 332;
sl ,cl ,zwfotos ,afdr4 ,j-zw , 332, 338;

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sl	,cl	,zwfotos	,ontw10	,j-ontw1	, 344,	444;
sl	,cl	,zwfotos	,ontw20	,j-ontw1	, 344,	350;
sl	,cl	,zwfotos	,ontw11	,j-ontw1	, 350,	356;
sl	,cl	,zwfotos	,afdr11	,j-zw	, 356,	362;
sl	,cl	,zwfotos	,afdr12	,j-zw	, 362,	368;
sl	,cl	,zwfotos	,ontw13	,j-ontw1	, 368,	374;
sl	,cl	,film6	,ontwik1	,p-ontw1	, 326,	332;
sl	,cl	,foto	,groen8	,p-groen	, 332,	338;
sl	,cl	,foto	,blauw8	,p-blauw	, 338,	344;
sl	,cl	,zwfotos	,afdr10	,p-zw	, 344,	350;
sl	,cl	,zwfotos	,afdr20	,p-zw	, 350,	356;
sl	,cl	,filml	,ontwik1	,p-ontw1	, 362,	368;
sl	,cl	,zwfotos	,afdr18	,p-zw	, 368,	374;
sl	,cl	,foto	,rood8	,k-rood	, 326,	332;
sl	,cl	,film6	,rood	,k-rood	, 332,	340;
sl	,cl	,film6	,groen	,k-groen	, 340,	348;
sl	,cl	,film6	,blauw	,k-blauw	, 348,	356;
sl	,cl	,foto	,rood4	,k-rood	, 356,	362;
sl	,cl	,foto	,groen4	,k-groen	, 362,	368;
sl	,cl	,foto	,blauw4	,k-blauw	, 368,	374;
! day5						
sl	,cl	,zwfotos	,ontw14	,j-ontw1	, 426,	432;
sl	,cl	,zwfotos	,ontw15	,j-ontw1	, 432,	438;
sl	,cl	,zwfotos	,ontw16	,j-ontw1	, 438,	444;
sl	,cl	,zwfotos	,ontw17	,j-ontw1	, 444,	450;
sl	,cl	,zwfotos	,ontw8	,j-ontw1	, 450,	456;
sl	,cl	,zwfotos	,ontw19	,j-ontw1	, 456,	462;
sl	,cl	,zwfotos	,afdr13	,j-zw	, 468,	474;
sl	,cl	,zwfotos	,afdr2	,p-zw	, 426,	432;
sl	,cl	,zwfotos	,afdr14	,p-zw	, 432,	438;
sl	,cl	,zwfotos	,afdr15	,p-zw	, 438,	444;
sl	,cl	,zwfotos	,afdr16	,p-zw	, 444,	450;
sl	,cl	,zwfotos	,afdr17	,p-zw	, 450,	456;
sl	,cl	,zwfotos	,afdr8	,p-zw	, 456,	462;
sl	,cl	,zwfotos	,afdr19	,p-zw	, 462,	468;
sl	,cl	,foto	,blauw5	,k-blauw	, 426,	432;
sl	,cl	,foto	,groen5	,k-groen	, 432,	438;
sl	,cl	,foto	,rood5	,k-rood	, 438,	444;
sl	,cl	,filml	,rood	,k-rood	, 444,	452;
sl	,cl	,filml	,groen	,k-groen	, 452,	460;
sl	,cl	,filml	,blauw	,k-blauw	, 460,	468;