ProSim

PROSIMPLUS APPLICATION EXAMPLE

EXAMPLE OF USE OF AN EXTERNAL OPTIMIZATION ALGORITHM

EXAMPLE PURPOSE
This example illustrates the use of an external optimization algorithm in the ProSimPlus simulation environment. The communication interfaces with the external algorithm are detailed along with a short application example.

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CORRESPONDING PROSIMPLUS FILES	*PSPS_E26_EN – External optimizer example.pmp3*

Reader is reminded that this use case is only an example and should not be used for other purposes. Although this example is based on actual case it may not be considered as typical nor are the data used always the most accurate available. ProSim shall have no responsibility or liability for damages arising out of or related to the use of the results of calculations based on this example.

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1. INTRODUCTION

The ProSimPlus simulation environment contains in its standard library two optimization algorithms, the first one is based on a SQP method (Sequential Quadratic Programming) and the second is implementing an evolutionary algorithm (genetic algorithm). Both of them are only working with continuous variables corresponding to the operating parameters of the process to be modeled. With the aim to offer more flexibility to the end-user, a new feature has been developed in version 3.5.16 of ProSimPlus; it allows to use an external optimization algorithm that can handle any type of optimization problem (multi-objective with continuous, integer or logical variables) through an external dynamic library. This document presents an example of use of this feature.

In a first step, the operating mode of the standard ProSimPlus optimizer is reminded, then the second part is dedicated to the presentation of the communication interfaces and finally an example based on the MIDACO optimization algorithm (www.midaco-solver.com) is detailed. MIDACO uses an extended "Ant Colony Optimization" evolutionary algorithm and is able to deal with multi-objective problems with mixed variables.

2. OPERATING MODE OF THE PROSIMPLUS STANDARD OPTIMIZER

2.1. Principle

The main operating principle of the ProSimPlus optimizer rely on a sequence of back to back runs (called « runs in the MCN ») between the module itself and the unit operations belonging to the optimization loop. This operating mode rely on the fact that the optimizer needs to know the values of the objective functions and the constraints at different steps of the optimization process:

- At the start of the convergence process
- When the objective functions and the constraints are being evaluated for a set of iterative variables at the current iteration
- When the derivatives of the objective functions and of the constraints are being calculated through numerical perturbations between two successive iterations

The description of the problem to be solved and the parameters associated to the SQP algorithm are detailed in the user's manual to which one's will refer for any additional information, especially concerning the **Feasible Path** and **Unfeasible Path** approaches as well as for the multi-periods optimization.

Thus, it's the role of the optimization algorithm to deal with the current calculation phase and depending on the type of algorithm used, the number of calculation phases can be variable. An evolutionary algorithm, for example, does only functions evaluations for different populations and after mutation and crossing, restarts the evaluation process until it reaches the predefined maximum number of generations.

2.2. Management of "tear" streams

Without describing in full details the **Unfeasible Path** approach, one's must know that the presence of "tear" streams in the optimization loop impose to the optimizer to handle the variables associated with these "tear" streams as optimization variables and to write equality constraints related to these variables, in form of:

$$x - g(x) = 0$$

With: x Current value of the variable

$g(x)$ Value of the variable after a run in the MCN.

The variables associated to a “tear” stream are: the partial molar flowrates of the components involved in the simulation and possibly the temperature and the pressure of the stream. Generally the temperature is taken into account whereas the pressure is added only if the unit operation from which the stream is exiting is automatically adjusting the pressure (for example the “Pipe segment” unit).

Furthermore, the variables associated to the “tear” streams must be the first variables of the optimization variables array (action variables) and in the following order:

Partial molar flowrate of the component #1 in the “tear” stream #1

Partial molar flowrate of the component #2 in the “tear” stream #1

…

Partial molar flowrate of the component #NC in the “tear” stream #1

Temperature of the “tear” stream #1 (if the temperature is selected as an optimization variable)

Pressure of the “tear” stream #1 (if the pressure is selected as an optimization variable)

….

The other optimization variables (outlet information streams from the “Optimization” unit) come after.

The use of an external optimization algorithm does not deviate from this rule as soon as it’s the **Unfeasible Path** approach which is used.

The **Feasible Path** approach, which imposes the use of a “Constraints and recycles” unit, allows to ignore this rule, even if in this case the calculation sequence must then be manually supplied (see ProSimPlus user’s manual).

2.3. Management of information

The various information required by the “Optimization” unit, are transmitted thanks to information streams connected to the unit and in the following sequence:

- Inlet information
    1. Objective function
    2. Equality constraint #1
    3. …
    4. Equality constraint #**NE**
    5. Inequality constraint #1
    6. …
    7. Inequality constraint #**NI**
- Outlet information
    1. Action variable #1
    2. …
    3. Action variable #**NA**

In the standard version of the optimizer (SQP algorithm), only one objective function is allowed, this means that the multi-objective optimization is not possible. However, an external algorithm might be able to handle several objective functions, thus the possibility to connect several objective functions has been implemented. For the standard SQP algorithm, this limitation is still in use, whereas for an external algorithm up to 10 objective functions (i.e. inlet information streams) can be connected to perform a multi-objective optimization.

2.4. Parameters

In order to offer the best user-friendliness in the use of an external algorithm, most of the standard parameters of the "Optimization" unit have been kept and can be used along with the external algorithm. These parameters are the following ones:

- Selection of the "tear" streams
- Selection of the parameters associated to the « tear » streams: bounds and increments for a possible sensitivity analysis
- Parameters relating to the optimization variables (action variables) : bounds, increments and types of increments for the sensitivity analysis
- General numerical parameters: maximum number of runs in the MCN, maximum number of iterations, intermediate printings step, number of rest steps, number of equality constraints, number of periods

Concerning the external algorithm-specific parameters, they are available in a « spreadsheet » like grid, allowing to adapt to the specificity of each external algorithm by offering the best flexibility of use.

3. COMMUNICATION INTERFACES WITH THE EXTERNAL ALGORITHM

Two communication interfaces are available, respectively for the calculation itself and for the printing of the results. They are detailed hereafter.

3.1. Calling interface for the solving

The calling interface used during the solving, is presented below:

```
integer(4) function OPTI(PAR,NPT,ITEMAX,NAPM,IALP,ITER,KOPT,INFO, &
                         NCO,NCI,NVA,NF,F,C,X,XL,XU,AC,G,CN) result(rc)
!dec$ attributes stdcall, reference, alias:'OPTI', dllexport :: OPTI

    integer(4), intent(in)    :: NPT, ITEMAX, NAPM, IALP(NVA), NCO, NCI, NVA, NF
    integer(4), intent(inout) :: ITER, KOPT, INFO
    real(8),    intent(inout) :: PAR(NPT)
    real(8),    intent(in)    :: F(NF), C(NCO), XL(NVA), XU(NVA), AC(NVA)
    real(8),    intent(inout) :: X(NVA), G(NF,NVA), CN(NCO,NVA)
```

The calling convention used is **STDCALL** and the arguments are passed by reference. The name of the entry point is imposed and must be **OPTI** (in uppercase).

The meaning of the function arguments is given in the following table:

Name	Type	Size (bytes)	I/O	Dimension	Description
NPT	Integer	4	I	1	Number of user parameters
ITEMAX	Integer	4	I	1	Maximum number of iterations
NAPM	Integer	4	I	1	Maximum number of runs in the MCN
IALP	Integer	4	I	NVA	Types of increment of the sensitivity analysis IALP(i)=1 : Absolute, IALP(i)=2 : Proportional
NCO	Integer	4	I	1	Number of constraints
NCI	Integer	4	I	1	Number of inequality constraints
NVA	Integer	4	I	1	Number of optimization variables
NF	Integer	4	I	1	Number of objective functions
ITER	Integer	4	I/O	1	Current iteration count
KOPT	Integer	4	I/O	1	Index of the calculation phase
INFO	Integer	4	O	1	Information relative to the calculation stop
PAR	Float	8	I/O	NPT	Array of parameters for the external algorithm
F	Float	8	I	NF	Array of the objective functions
C	Float	8	I/O	NCO	Array of the constraints
XL	Float	8	I	NVA	Array of the lower bounds of the action variables
XU	Float	8	I	NVA	Array of the upper bounds of the action variables
AC	Float	8	I	NVA	Array of the increments for the sensitivity analysis
X	Float	8	I/O	NVA	Array of the optimization variables
G	Float	8	I/O	(NF,NVA)	Work array for the storage of the derivatives of the objective functions with respect to the optimization variables
CN	Float	8	I/O	(NCO,NVA)	Work array for the storage of the derivatives of the constraints with respect to the optimization variables

Note: The **G()** and **CN()** arrays are provided as storage arrays for the derivatives of the objective functions and derivatives of the constraints with respect to the optimization variables and may not be used depending on the optimization algorithm used.

At each call, the function must return an integer value indicating the current state of the calculation.

The return code can take the following values:

OPTI_RUNNING	-1	Optimization running
OPTI_CONVERGED	0	Optimization ended
OPTI_FAILED	2	Optimization failed

Furthermore, during the calculation, the **KOPT** variable is used by the **OPTI** function to know and manage the current calculation state. The **KOPT** variable is set to 0 at first call (which allows to perform some initializations or to execute specific code only once) and must be set to any non-zero value by the function. The values are let free to the developer's needs. At the end of the optimization process, the **KOPT** variable must be reset to zero (i.e. when the return code has been set to **OPTI_CONVERGED** or **OPTI_FAILED**).

Then, the **INFO** variable is used to know the reason of the calculation stop. This variable can take the following values:

INFO	Description
1	Optimization successful
≠ 1	Failure of the optimization

3.1. Calling interface for the printings

The calling interface used for the printings, is presented below:

```
subroutine IOPTI(PAR,NPT)
!dec$ attributes stdcall, reference, alias:'IOPTI', dllexport :: IOPTI

    integer(4), intent(in) :: NPT
    real(8),    intent(in) :: PAR(NPT)
```

The calling convention used is **STDCALL** and the arguments are passed by reference. The name of the entry point is imposed and must be **IOPTI** (in uppercase).

The meaning of the arguments is the same as for the main calling interface (**OPTI** function above).

Note: The entry point is optional, if it is not available in the dynamic link library, it will not be called but this will not prevent the optimization process to run. In the case it is available, the printings must be made into specific file, named **IMPO_OPTI.tmp** and being located in the temporary folder of the current user. This file must be open in the **IOPTI** subroutine and closed before leaving it in order to the calling process to be able to read its content and to destroy it after. This file can be used, for example, to transfer the contents of the output file(s) generated by the external algorithm to the simulation report. If needed, the external algorithm-specific parameters are available in the arguments list but must not be modified (read only).

3.2. Management of objective functions

The **F()** array contains the value(s) of the objective function(s) for the current optimization process. It contains the values transmitted to the ”Optimization” unit through information stream(s) connected to the connection ports labelled “Objective function i”. The **F()** array is updated at each call with the current value(s) of the objective function(s). In the case of an optimization algorithm requiring to evaluate the derivatives of the objective function(s) with respect to the optimization variables, it will be necessary to save the contents of this array into a local array at the beginning of every new iteration (i.e. once the evaluation of the objective function(s) and the constraints has been performed).

3.3. Management of constraints

The **G()** array contains the values of the constraints for the current optimization process. It contains the values of the equality constraints followed by those of the inequality constraints. In the case the “Optimization” unit handles by itself the “tear” streams, i.e. in the case of the **Unfeasible Path** approach, the equality constraints are first made up with the constraints relating to the « tear » streams followed by the constraints transmitted to the “Optimization” unit through the information streams connected to the connection ports labelled “Constraint i”.

Furthermore, the connection ports, labelled “Constraint 1” to “Constraint NE” must compulsorily be used for the **NE** equality constraints and the ports “Constraint NE+1” to “Constraint NE+NI” by those associated to the inequality constraints.

As for the objective function(s), the **G()** array is updated at each call with the current values of the constraints. In the case of an optimization algorithm requiring to evaluate the derivatives of the constraints with respect to the optimization variables, it will be necessary to save the contents of this array into a local array at the beginning of every new iteration (i.e. once the evaluation of the objective function(s) and the constraints has been performed).

3.3.1. Inequality constraints

The inequality constraints must be written in such a way that the value of the constraint is negative when it is satisfied, which is the normal behavior used in the standard optimization algorithm (SQP). For example, if a constraint is expressed as:

$$a \leq f_i \leq b$$

Then, the **G()** array will contains the following expressions:

$$G(k) = a - f_i$$

$$G(k+1) = f_i - b$$

In the case where the external algorithm uses the reverse way (like for the MIDACO algorithm), their sign must be changed before each call to the external algorithm solving routine.

3.4. Intermediate printings

During the calculation phase, it is possible to print some intermediate results into the ProSimPlus history file (extension .HIS). These printings are performed through the use of a temporary file, named **IMPI_OPTI.tmp** being located in the temporary folder of the current user. This file must be open at each call to the **OPTI** function and closed before leaving it so that the calling process can read its content and destroy it after.

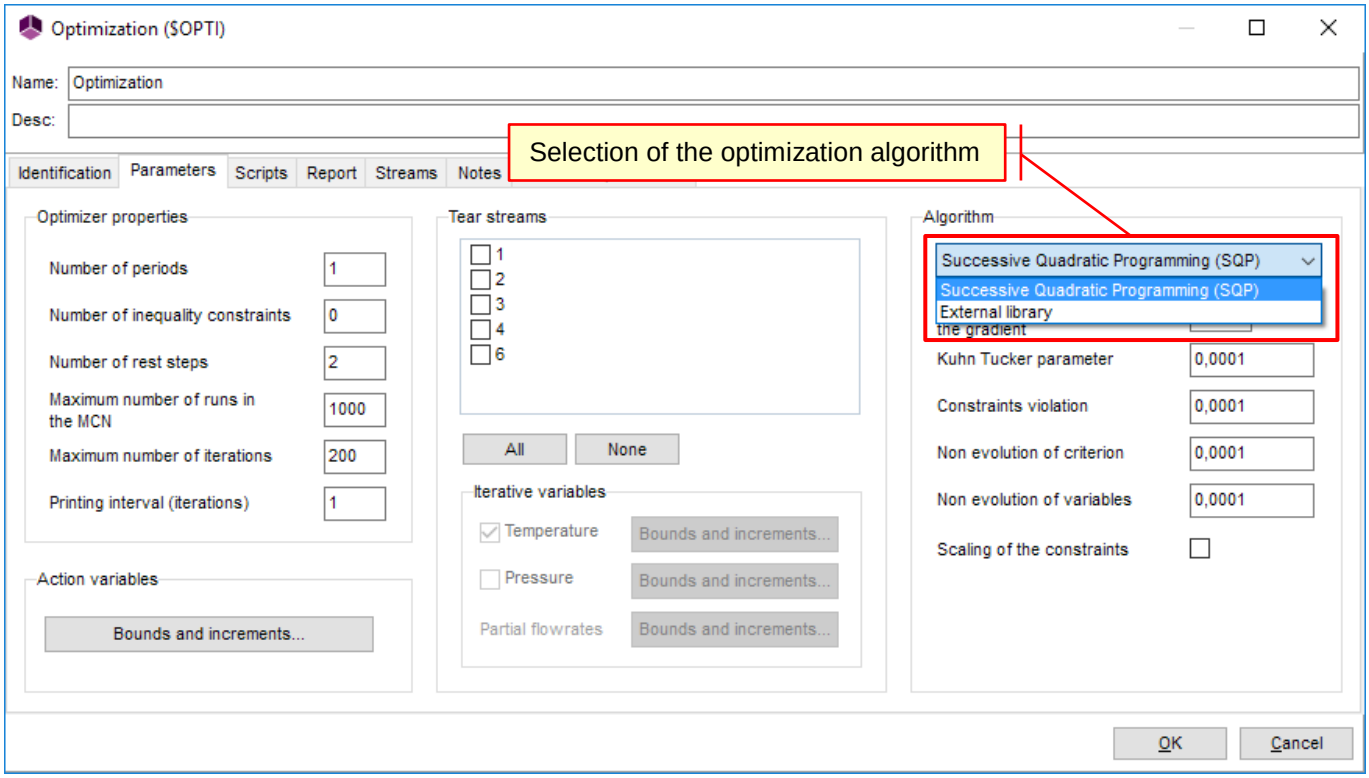
If no information is required, it is not necessary to create this file. This can be the case if the external algorithm manages its own output files, nevertheless in such a case the content of these files could not be inserted neither in the simulation report nor in the history file.

3.5. Graphical User Interface

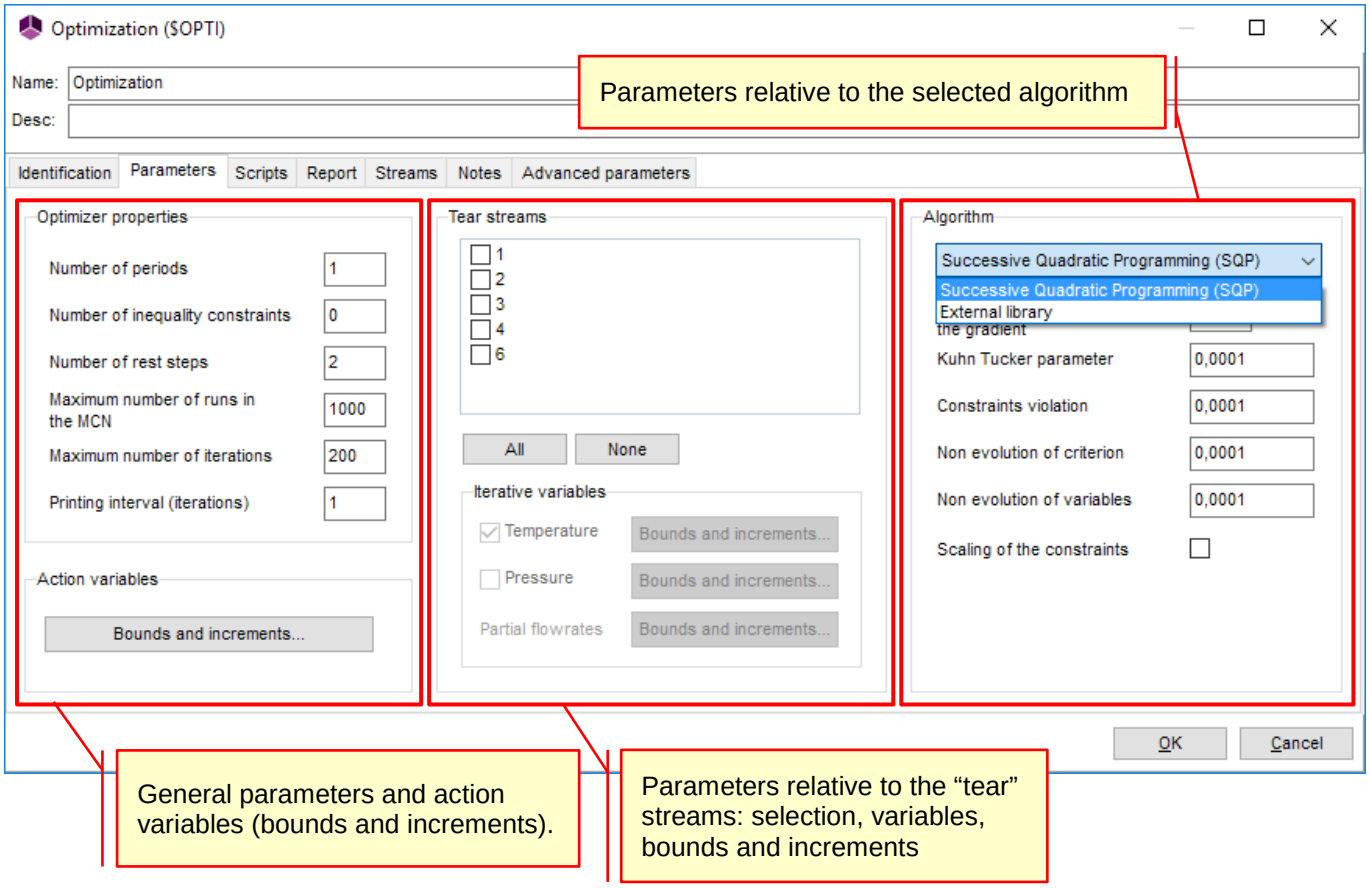
The following screenshots present the modifications realized in the ProSimPlus “Optimization” unit in order to make possible the use on an external optimization algorithm.

The main tab, containing the parameters has been redesigned in order to clearly split the general parameters from the parameters relating to the “tear” streams (**Unfeasible Path** approach) from those relating to the selected optimization algorithm.

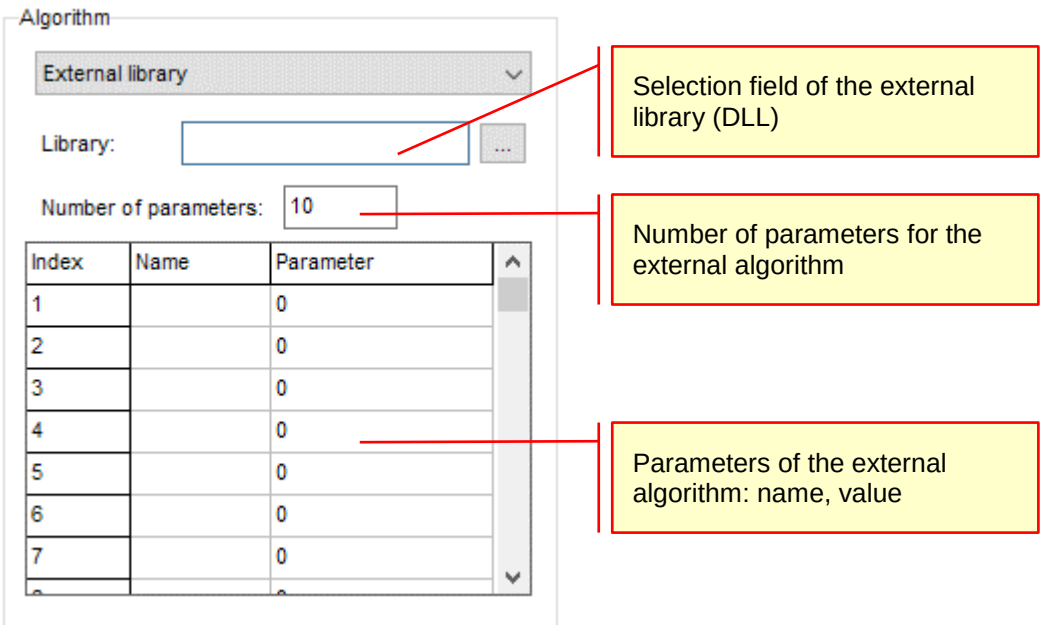
Selection of the optimization algorithm



Other parameters of the “Optimization” unit



Parameters relative to the external algorithm



3.6. Simulation report

The simulation report displays the generic elements of the “Optimization” unit, like the data relative to the objective function(s), to the constraints and to the optimization variables. It displays also the items relative to the standard numerical parameters of the unit: action variables and bounds, “tear” streams and bounds. Finally it displays the user-defined parameters as they are defined in the grid with their names and numerical values. If a printing subroutine is implemented the outputs made in this procedure are included at the end of the “standard” printings.

4. USE CASE: THE MIDACO SOLVER

This section details a use case based on the implementation of an external algorithm. The solver selected has been developed by M. Schlueter and M. Munemoto from the Hokkaido University. It implements a general purpose algorithm for solving mono and multi-objective problems, initially developed for solving nonlinear problems with mixed variables (MINLP). In its current version, it is based on an evolutionary algorithm known as « **Ant Colony Optimization** », from which it takes its name: **M**ixed **I**nteger **D**istributed **A**nt **C**olony **O**ptimization.

An evaluation version, limited to up to 4 optimization variables is available on the following web-site www.midaco-solver.com. It is the version which has been used in this example.

The problem used as a test case is a simple optimization problem for which the analytical solution is known as well as the solution provided by the ProSimPlus standard SQP algorithm.

It is a purely theoretical problem described as follows: a process has 4 feeds which are mixed and the aim is to maximize the following function which depends on the flowrates of these feeds.

$$f = -(f_1 + f_2 + f_3 + f_4)$$

With:

$$f_1 = \frac{1}{(x_1 - 1.111)^2 + 0.1}, \qquad f_2 = \frac{1}{(x_2 - 2.222)^2 + 0.1}$$

$$f_3 = \frac{1}{(x_3 - 3.333)^2 + 0.1}, \qquad f_4 = \frac{1}{(x_4 - 4.444)^2 + 0.1}$$

And

x_i Total molar flowrate of the feed #i

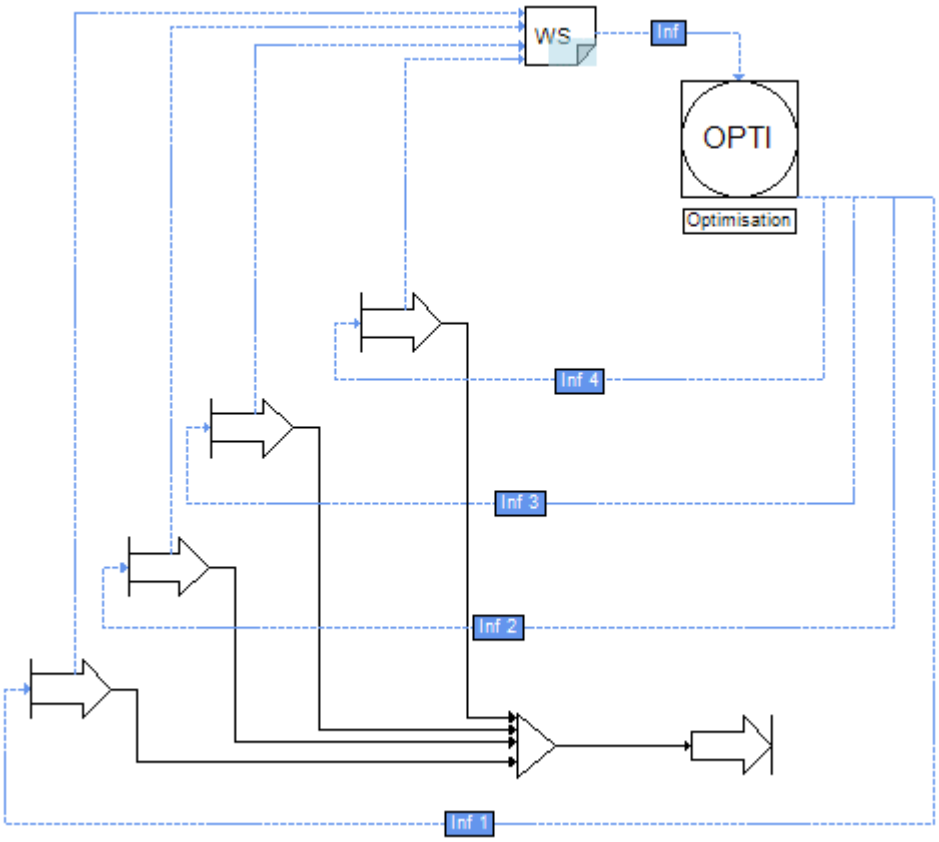
The analytical solution is:

$$f = -40$$

And $x_1 = 1.111, \quad x_2 = 2.222$

$x_3 = 3.333, \quad x_4 = 4.444$

The objective function is calculated thanks to a script unit which takes the values of the feeds flowrates (inlet information streams) and the “Optimization” unit calculates them. It is a problem without constraints and the ProSimPlus flow diagram is presented hereafter:



The variables are bounded between 0.1 kmol/h and 10 kmol/h

The use of the ProSimPlus standard SQP algorithm with the default numerical parameters (except for the bounds) gives the following results:

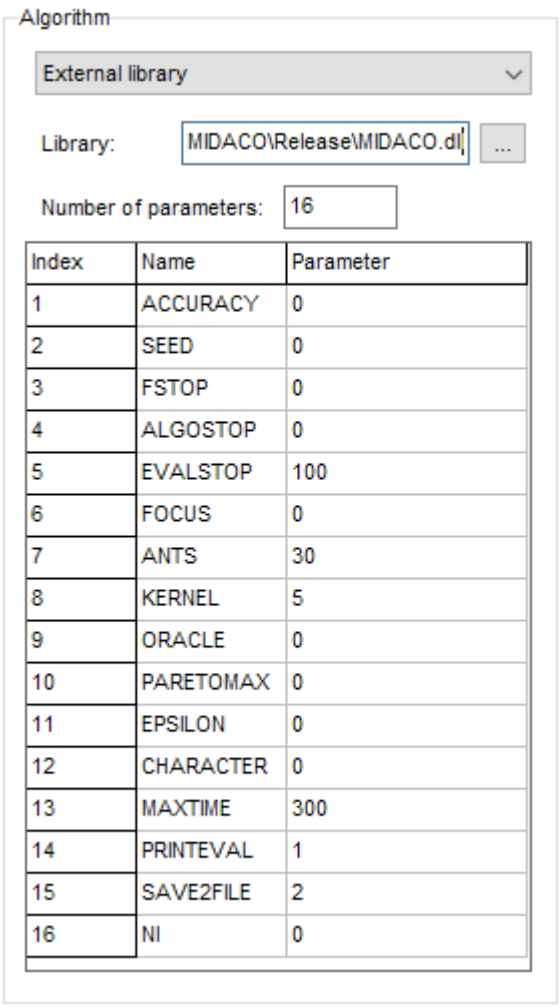
```
  SUCCESSIVE QUADRATIC PROGRAMMING ALGORITHM
  ******************************************


NUMBER OF VARIABLES OF THE PROBLEM.....................    4
     AMONG WHICH   0 ARE TEAR STREAM VARIABLES
             AND   4 ARE OPTIMIZATION VARIABLES

NUMBER OF CONSTRAINTS OF THE PROBLEM...................    0
     NUMBER OF EQUALITY CONSTRAINTS....................    0
     NUMBER OF INEQUALITY CONSTRAINTS..................    0

DERIVATES OF THE FUNCTION ARE COMPUTED
     - BY 1ST ORDER FINITE DIFFERENCES

NUMERICAL PARAMETERS:
     MAXIMUM NUMBER OF MAJOR ITERATIONS.................  200
     MAXIMUM NUMBER OF SEQUENCE CALCULATIONS............ 1000
     TOLERANCE ON KUHN-TUCKER ERROR..................... 1.000000E-04
     TOLERANCE FOR NON-EVOLUTION OF THE VARIABLES....... 1.000000E-04
     TOLERANCE FOR NON-EVOLUTION OF THE FONCTION........ 1.000000E-04

RESULTS:
     NUMBER OF ITERATIONS...............................   23
     NUMBER OF RUNS IN THE PROCESS......................  130
     VALUE OF THE OBJECTIVE FUNCTION:
       - Inf........................................... -39.9992
```



```
KUHN-TUCKER ERROR.............................. 1.505471E-05
PARAMETER FOR CONSTRAINTS VIOLATION.............  0.00000
CONDITION NUMBER................................  1.04448


--> THE LAST ITERATION GIVES AN OPTIMAL SOLUTION

                              VALUE      LOW. BOUND   UPP. BOUND  PERTURBATION     TYPE

OPTIMIZATION VARIABLES:
-----------------------
 1: Inf 1                    1.110       0.1000        10.00       1.0000E-03  PROPORTIONAL
 2: Inf 2                    2.221       0.1000        10.00       1.0000E-03  PROPORTIONAL
 3: Inf 3                    3.331       0.1000        10.00       1.0000E-03  PROPORTIONAL
 4: Inf 4                    4.442       0.1000        10.00       1.0000E-03  PROPORTIONAL
```

The source code of the procedure calling the MIDACO algorithm is provided in appendix 1.

The screenshot below shows the specific algorithm-parameters, the first 12 of them correspond to the **PARAM()** array of the MIDACO routine, the following ones are used to access to other parameters and are detailed in the MIDACO user's guide (MAXTIME, PRINTEVAL, SAVE2FILE and NI).



Index	Name	Parameter
1	ACCURACY	0
2	SEED	0
3	FSTOP	0
4	ALGOSTOP	0
5	EVALSTOP	100
6	FOCUS	0
7	ANTS	30
8	KERNEL	5
9	ORACLE	0
10	PARETOMAX	0
11	EPSILON	0
12	CHARACTER	0
13	MAXTIME	300
14	PRINTEVAL	1
15	SAVE2FILE	2
16	NI	0

In the studied example, the results obtained strongly depend on the values given to the parameters **ANTS** and **KERNEL** which with the default values (0 and 0) lead to a non-optimal solution.

With the above parameters, the results obtained are presented hereafter.


```
  EXTERNAL OPTIMIZATION ALGORITHM
  ******************************


NUMBER OF VARIABLES OF THE PROBLEM.....................    4
     AMONG WHICH   0 ARE TEAR STREAM VARIABLES
             AND   4 ARE OPTIMIZATION VARIABLES

NUMBER OF CONSTRAINTS OF THE PROBLEM...................    0
     NUMBER OF EQUALITY CONSTRAINTS....................    0
     NUMBER OF INEQUALITY CONSTRAINTS..................    0

PARAMETERS OF THE EXTERNAL ALGORITHM:
     ACCURACY.........................................  0
     SEED.............................................  0
     FSTOP............................................  0
     ALGOSTOP.........................................  0
     EVALSTOP.........................................  100.000
     FOCUS............................................  0
     ANTS.............................................  30.0000
     KERNEL...........................................  5.00000
     ORACLE...........................................  0
     PARETOMAX........................................  0
     EPSILON..........................................  0
     CHARACTER........................................  0
     MAXTIME..........................................  300.000
     PRINTEVAL........................................  1.00000
     SAVE2FILE........................................  2.00000
     NI...............................................  0

NUMERICAL PARAMETERS:
     MAXIMUM NUMBER OF MAJOR ITERATIONS.................  200
     MAXIMUM NUMBER OF SEQUENCE CALCULATIONS............ 1000

RESULTS:
     NUMBER OF ITERATIONS...............................  499
     NUMBER OF RUNS IN THE PROCESS......................  501
     VALUE OF THE OBJECTIVE FUNCTION:
       - Inf........................................... -39.9954


--> THE LAST ITERATION GIVES AN OPTIMAL SOLUTION


                              VALUE      LOW. BOUND   UPP. BOUND  PERTURBATION     TYPE

OPTIMIZATION VARIABLES:
-----------------------
 1: Inf 1                   1.114       0.1000        10.00       1.0000E-03  PROPORTIONAL
 2: Inf 2                   2.218       0.1000        10.00       1.0000E-03  PROPORTIONAL
 3: Inf 3                   3.329       0.1000        10.00       1.0000E-03  PROPORTIONAL
 4: Inf 4                   4.441       0.1000        10.00       1.0000E-03  PROPORTIONAL
```

One can note that the parameters described in the graphical user interface are printed in the simulation report.

For this example, an additional printing routine is implemented, which transfers in the simulation report the content of the MIDACO_SOLUTION.TXT file when the variable SAVE2FILE has a non-zero value. The source code of the printing routine is provided in appendix 2.

APPENDIX 1 – SOURCE CODE OF THE EXTERNAL OPTI ROUTINE

```
integer(4) function OPTI(PAR,NPT,ITEMAX,NAPM,IALP,ITER,KOPT,INFO, &
                         NCO,NCI,NVA,NF,F,C,X,XL,XU,AC,G,CN) result(rc)
!dec$ attributes stdcall, reference, alias:'OPTI', dllexport :: OPTI
    use IFWIN

    implicit none

    integer(4), intent(in)    :: NPT, ITEMAX, NAPM, IALP(NVA), NCO, NCI, NVA, NF
    integer(4), intent(inout) :: ITER, KOPT, INFO
    real(8),    intent(inout) :: PAR(NPT)
    real(8),    intent(in)    :: F(NF), C(NCO), XL(NVA), XU(NVA), AC(NVA)
    real(8),    intent(inout) :: X(NVA), G(NF,NVA), CN(NCO,NVA)

    integer(4), parameter :: OPTI_CONVERGED =  0
    integer(4), parameter :: OPTI_FAILED    =  2
    integer(4), parameter :: OPTI_RUNNING   = -1

    ! Dimensions of the optimization problem
    integer(4) O, N, NI, M, ME

    ! MIDACO information and stop flags
    integer(4) IFLAG, ISTOP
    ! MIDACO parameter
    real(8) PARAM(12)
    ! MIDACO integer 'IW' and real'RW' workspace and pareto front 'PF'
    integer(4), parameter :: LIW = 10000
    integer(4), parameter :: LRW = 10000
    integer(4), parameter :: LPF = 10000
    integer(4) IW(LIW)
    real(8) RW(LRW),PF(LPF)
    ! Parameter for stopping criteria, printing and license
    integer(4) MAXTIME, MAXEVAL, PRINTEVAL, SAVE2FILE, I
    character(len=60) :: KEY = 'MIDACO_LIMITED_VERSION___[CREATIVE_COMMONS_BY-NC-ND_LICENSE]'
    !
    real(8), allocatable :: C1(:)
    integer(BOOL) rcDel
    logical Found
    integer(4) IOS, rcTemp, szTempPath
    character(len=256) TempPath

    if (KOPT /= 0) goto 100

    !CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
    !CC Step 0: Deleting possible output files     CCCCCCCCCCCCCCCCCCCCCCCC
    !CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC

    inquire(FILE='MIDACO_HISTORY.TXT', exist=Found)
    if (Found) rcDel = DeleteFile('MIDACO_HISTORY.TXT')

    inquire(FILE='MIDACO_SOLUTION.TXT', exist=Found)
    if (Found) rcDel = DeleteFile('MIDACO_SOLUTION.TXT')

    inquire(FILE='MIDACO_SCREEN.TXT', exist=Found)
    if (Found) rcDel = DeleteFile('MIDACO_SCREEN.TXT')

    inquire(FILE='MIDACO_PARETOFRONT.TXT', exist=Found)
    if (Found) rcDel = DeleteFile('MIDACO_PARETOFRONT.TXT')

    !CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
    !CC Step 1: Problem definition     CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
```



```
!CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
!
!     Step 1.A : Problem dimensions
!     CCCCCCCCCCCCCCCCCCCCCCCCCCCC
O  = NF             ! Number of objectives
N  = NVA            ! Number of variables (in total)
NI = nint(PAR(16))  ! Number of integer variables (0 <= NI <= N)
M  = NCO            ! Number of constraints (in total)
ME = NCO - NCI      ! Number of equality constraints (0 <= ME <= M)

if (M /= 0) then
    if (allocated(C1)) deallocate(C1)
    allocate(C1(M))
else
    if (allocated(C1)) deallocate(C1)
    allocate(C1(1))
end if
C1(:) = 0.D0

!CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
!CC Step 2: Choose stopping criteria and printing options    CCCCCCCCCCC
!CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
!
! Step 2.A : Stopping criteria
! CCCCCCCCCCCCCCCCCCCCCCCCCCC
MAXEVAL = NAPM              ! Maximum evaluation budget (e.g. 1000000)
MAXTIME = nint(PAR(13))     ! Maximum time limit (e.g. 300 = 10 Min)
!
! Step 2.B : Printing options
! CCCCCCCCCCCCCCCCCCCCCCCCCC
PRINTEVAL = nint(PAR(14))   ! Print-Frequency for current best solution (e.g. 1000)
SAVE2FILE = nint(PAR(15))   ! Save SCREEN and SOLUTION to TXT-files [0=NO/1=YES]

!CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
!CC Step 3: Choose MIDACO parameters (FOR ADVANCED USERS)    CCCCCCCCCCC
!CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
!
!PARAM( 1) = 0.D0  ! ACCURACY
!PARAM( 2) = 0.D0  ! SEED
!PARAM( 3) = 0.D0  ! FSTOP
!PARAM( 4) = 0.D0  ! ALGOSTOP
!PARAM( 5) = 0.D0  ! EVALSTOP
!PARAM( 6) = 0.D0  ! FOCUS
!PARAM( 7) = 0.D0  ! ANTS
!PARAM( 8) = 0.D0  ! KERNEL
!PARAM( 9) = 0.D0  ! ORACLE
!PARAM(10) = 0.D0  ! PARETOMAX
!PARAM(11) = 0.D0  ! EPSILON
!PARAM(12) = 0.D0  ! CHARACTER
do I=1,12
   PARAM(I) = PAR(I)
end do

ITER = -1

! Print MIDACO headline with basic information
call MIDACO_PRINT(1,PRINTEVAL,SAVE2FILE,IFLAG,ISTOP,F,C1,X,XL, &
                  XU,O,N,NI,M,ME,RW,PF,MAXEVAL,MAXTIME,PARAM,1,0,KEY)

KOPT = 15

!CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
!
!       Call MIDACO by Reverse Communication
```



```
    !
    !CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC

100 continue
    ! Incrementation of the iteration counter
    ITER = ITER + 1
    ! Sign change for the inequality constraints
    if (M /= 0) then
        C1(1:M) = C(1:M)
        do I=ME+1,M
           C1(I) = -C1(I)
        end do
    end if

    ! Opening the specific history file (if SAVE2FILE >= 2)
    if (SAVE2FILE >= 2) then
        szTempPath = len(TempPath)
        rcTemp = GetTempPath(szTempPath, TempPath)
        if (rcTemp > szTempPath .or. rcTemp == 0) then
            TempPath = '.\'
            rcTemp = 2
        end if
        open(UNIT=888,FILE=TempPath(1:rcTemp)//'IMPI_OPTI.tmp',STATUS='REPLACE',IOSTAT=IOS)
        write(888,1)
 1      format('#########################################################',/, &
               '### SOLUTION FORMAT:     F(1:O)    G(1:M)    X(1:N)   ###',/, &
               '#########################################################')
        write(888,2) O,M,N
 2      format('#',/, &
               '#        O         M         N  ',/, &
               '#',/, &
               3I10)
        call SAVE_HISTORY(1,O,N,M,F,C1,X,888,ISTOP)
        close(888)
    end if

    call MIDACO(1,O,N,NI,M,ME,X,F,C1,XL,XU,IFLAG, &
   &            ISTOP,PARAM,RW,LRW,IW,LIW,PF,LPF,KEY)

    ! Call MIDACO printing routine
    call MIDACO_PRINT(2,PRINTEVAL,SAVE2FILE,IFLAG,ISTOP,F,C1,X, &
                      XL,XU,O,N,NI,M,ME,RW,PF,MAXEVAL,MAXTIME,PARAM,1,0,KEY)

    if (ISTOP == 0) then
        rc = OPTI_RUNNING
    else
        select case (IFLAG)
        case (1:7)
            rc = OPTI_CONVERGED
        case default
            rc = OPTI_FAILED
        end select
        select case (IFLAG)
        case (1, 3, 5, 7)
            INFO = 1
        case default
            INFO = IFLAG
        end select
        KOPT = 0
        if (allocated(C1)) deallocate(C1)
    end if

end function OPTI
```


APPENDIX 2 – SOURCE CODE OF THE EXTERNAL IOPTI ROUTINE

```
subroutine IOPTI(PAR,NPT)
!dec$ attributes stdcall, reference, alias:'IOPTI', dllexport :: IOPTI
    use IFWIN

    implicit none

    integer(4), intent(in) :: NPT
    real(8),    intent(in) :: PAR(NPT)

    integer(4) IOS, rc, SAVE2FILE, szTempPath

    character(len=256) TempPath, LINE

    SAVE2FILE = nint(PAR(15))

    if (SAVE2FILE /= 0) then
        open(UNIT=889,FILE='MIDACO_SOLUTION.TXT',STATUS='OLD',IOSTAT=IOS)
        if (IOS /= 0) return
        szTempPath = len(TempPath)
        rc = GetTempPath(szTempPath, TempPath)
        if (rc > szTempPath .or. rc == 0) then
            TempPath = '.\'
            rc = 2
        end if
        open(UNIT=888,FILE=TempPath(1:rc)//'IMPO_OPTI.tmp',STATUS='REPLACE',IOSTAT=IOS)
        do while (.not.eof(889))
           read(889,'(A)') LINE
           write(888,'(A)') LINE
        end do
        close(888)
        close(889)
    end if

end subroutine IOPTI
```

