IBM ILOG OPL V6.3

IBM ILOG OPL — From OR to OPL and ODM

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Acknowledgement

The language manuals are based on, and include substantial material from, The OPL Optimization Programming Language by Pascal Van Hentenryck, © 1999 Massachusetts Institute of Technology.

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From OR to OPL and ODM

Provides an overview of IBM® ILOG® OPL and its main features for OR experts who are not familiar with IBM ILOG OPL and IBM ILOG ODM.

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A quick start to OPL

A description of OPL for users who are familiar with optimization problems but not with the OPL product.

In this section

Summary: what you can do with the OPL IDE

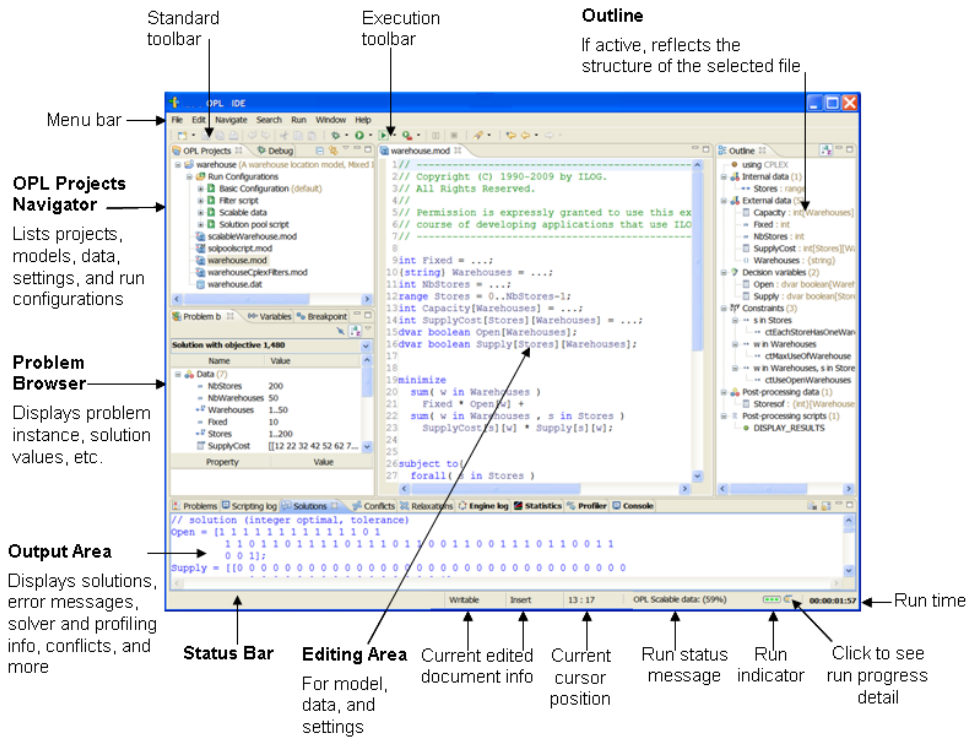
Summarizes the features and capabilities of OPL.

What is in the Quick Start?

This Quick Start is written for OR experts who are not familiar with the IBM® ILOG® OPL approach for development and deployment of optimization models. It starts from a well known, hands-on example based on the *P-Median* warehouse allocation problem. More detailed information on the concepts, terms, and procedures presented in this section is provided throughout the OPL documentation set, in particular in the *Glossary* and in *Getting Started with the IDE*.

The Main window

Tooltips appear when you move the pointer over most elements of the main window.


Standard toolbar
Execution toolbar
Outline
If active, reflects the structure of the selected file
Menu bar
OPL Projects Navigator
Lists projects, models, data, settings, and run configurations
Problem Browser
Displays problem instance, solution values, etc.
Output Area
Displays solutions, error messages, solver and profiling info, conflicts, and more
Status Bar
Editing Area
For model, data, and settings
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Current cursor position
Run status message
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OPL IDE
File Edit Navigate Search Run Window Help
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Debug
warehouse.mod
Outline
Problems
Scripting log
Solutions
Conflicts
Relaxations
Engine log
Statistics
Profiler
Console
Writable
Insert
13 : 17
OPL Scalable data: (59%)
00:00:01:57

```
// -----------------------------------------------------------
// Copyright (C) 1990-2009 by ILOG.
// All Rights Reserved.
//
// Permission is expressly granted to use this ex
// course of developing applications that use ILO
// -----------------------------------------------------------

int Fixed = ...;
{string} Warehouses = ...;
int NbStores = ...;
range Stores = 0..NbStores-1;
int Capacity[Warehouses] = ...;
int SupplyCost[Stores][Warehouses] = ...;
dvar boolean Open[Warehouses];
dvar boolean Supply[Stores][Warehouses];


minimize
  sum( w in Warehouses )
    Fixed * Open[w] +
  sum( w in Warehouses , s in Stores )
    SupplyCost[s][w] * Supply[s][w];


subject to{
  forall( s in Stores )
```

```
// solution (integer optimal, tolerance)
Open = [1 1 1 1 1 1 1 1 1 1 1 1 0 1
         1 1 0 1 1 0 1 1 1 1 0 1 1 1 0 1 1 0 0 1 1 0 0 1 1 1 0 1 1 0 0 1 1
         0 0 1];
Supply = [[0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
```

This annotated screenshot is provided just to give you an idea of what the OPL integrated development environment (IDE) looks like as you are working with it.

Additional information on the OPL IDE and how to work with it are presented in *Getting Started with the OPL IDE* and in the *IDE Reference* manual.

Understanding OPL projects

OPL handles project files, data files, model files, setting files, and run configurations.

In this section

Projects / folders

IBM® ILOG® OPL uses the concept of a *project* to associate a model (`.mod`) file with, usually, one or more data (`.dat`) files and one or more settings (`.ops`) files.

A project containing only a single model file is valid; data and settings files are optional. However, one project can contain several sets of model, data and settings files, the relationships between them maintained using *run configurations*.

The *model file* declares data elements but does not necessarily initialize them. The *data files* contain the initialization of data elements declared in the model.

The `.project` file in the root folder for the OPL project organizes all the related model, data and settings files. Run configurations, which are maintained in an `.oplproject` file, also provide a convenient way to maintain the relationship between related files and runtime options for the environment (see also the *Run configurations* section).

When you are about to write a new model in IBM ILOG, the dialog box that appears allows you to name your project, give your project a description, and choose whether you want to create a data file or a settings file. The description of the project may be useful later to better differentiate projects with similar names. This is explained in detail in *Getting Started with the OPL IDE* and in the *IDE Reference* manual.

A minimal project has:

♦ one model file

♦ one default run configuration referencing that same model file

A typical project has:

♦ one or more model files

♦ any number of data files or no data file

♦ any number of settings files or no settings file

♦ one or more run configurations referencing various combinations of those model, data, and settings files. (A run configuration cannot have more than one model file.)

Model files

Model (`.mod`) files contain all your OPL statements. The data and the objective function are not mandatory and there may be more optional components, such as scripting statements. Note that you can also generate a model file in a compiled form (`.opl`) from the IDE for execution through the OPL interface libraries (see *Generating a compiled model*). The components of a model file are covered in the following sections.

Declarations of data

Data declarations allow you to name your data so that you can reference them easily in your model. For example, if your data in a table define the cost of shipping one unit of material from location *i* to location *j*, you might want to call your item of data $cost_{ij}$ where *i*=1, . . . , *n* and *j*=1, . . . , *n* and *n* is the number of locations in your model. You tell OPL that your model uses this data by declaring:

```
int n = . . . ;
float cost[1..n][1..n] = . . . ;
```

The **...** (ellipsis) means that the values for your table are located in a data file, which must be listed in the current project.

You could also list the data explicitly in the model file. However, it is recommended that you construct model files without specifying values for data so that you can later easily solve many instances of the same model by simply changing the data file. See also the Run configurations section.

Note that the `int` type declared means that the numbers in the data file must be integers. If the numbers in the data file are floating-point numbers, use the `float` type instead.

Declarations of decision variables

In OPL context, as opposed to IBM ILOG Script and to the general programming context, variables are decision variables. Declarations of decision variables name and give the type of each variable in the model. For example, if you want to create a variable that equals the amount of material shipped from location *i* to location *j*, you can create a variable named $ship_{ij}$.

```
dvar float+ ship[1..n][1..n];
```

That statement declares an array of non-negative floating-point variables. (That is what `float+` means). The `dvar` keyword indicates that you are declaring a decision variable.

An objective function

The objective function is a function that you want to optimize. This function must consist of variables and data that you have declared earlier in the model file. The objective function is introduced by either the `minimize` or the `maximize` keyword. For example,

```
minimize sum(i,j in 1..n) cost[i][j]*ship[i][j];
```

That statement indicates that you want to minimize the sum of the shipping costs for each origin-destination pair.

Constraints

Constraints indicate the conditions necessary for a feasible solution to your model. You declare constraints within a `subject to` block. For example,

```
subject to {
   forall(j in 1..n) sum(i in 1..n) ship[i][j] == demand[j];
}
```

That statement declares one set of constraints. There is a constraint for each destination. (That is what the `forall` keyword indicates.) The constraint for each destination states that the sum of material shipped to that destination must equal the demand at that destination. The symbol == indicates equals within a constraint block. The symbol <= indicates less than or equal to. The symbol >= indicates greater than or equal to.

Data files

You can organize large problems better by separating the model of the problem from the instance data, each set of data stored in a separate data file, with a `.dat` extension.

In this case, you store the instance data in one or more data files (`.dat`). Data files (`.dat`) store the values of the data used in the model. If you declare the data as suggested in this tutorial, your data file will look something like this:

```
n = 3;

c = [[0.0 1.5 2.3]
     [1.5 0.0 3.7]
     [2.3 3.7 0.0]];
```

Each data file may specify one or more connections to data sources, such as a relational database or a spreadsheet, to read and write data.

Settings files

Settings files (`.ops`) are where your user-defined values are stored when you decide to change the default values of OPL language options, constraint-programming (CP Optimizer) parameters, or mathematical-programming (CPLEX®) parameters.

OPL settings apply only to the model included in the run configuration, not to the submodels loaded and solved.

Run configurations

Run configurations are a way of handling model, data, and settings files within a project.

Basically, a run configuration is a variation of a given project for execution purposes. It combines at least a model file and, optionally, one or more data files and one or more settings files within the project, while addressing the same mathematical problem. You can define as many run configurations as you need within a given project. Typically, you use run configurations to test, improve, and fine-tune your OPL projects.

For example, you can:

♦ keep two sets of data: a simple one for quick prototyping and a larger one to work closer to your business case;

♦ keep one configuration for each set of MP options (CPLEX parameters) that makes sense for your problem.

Practically, run configurations appear as sublevels in the Projects tree.

Modeling the P-Median problem with OPL

The *P-Median* problem is a well known warehouse allocation problem in Operations Research. The problem can be stated very simply, like this: given a set of customers with known amounts of demand, a set of candidate locations for warehouses, and the distance between each pair of customer-warehouse, choose `P` warehouses to open that minimize the demand-weighted distance of serving all customers from those `P` warehouses.

A standard textbook would probably write out the P-Median problem like this:

Data

P	=	number of facilities to locate
I	=	set of customers
J	=	set of candidate locations for warehouses
hi	=	demand for customer i
dij	=	distance between customer i and candidate warehouse j

Decision variables

x_j	=	1 if candidate warehouse j is used; 0 otherwise
y_{ij}	=	1 if demand for customer i is satisfied by warehouse j; 0 otherwise

Objective

Minimize the demand-weighted distance of delivering to customers.

Or, expressed as an equation:

$$\min \sum_{i \in I} \sum_{j \in J} h_i d_{ij} y_{ij}$$

Constraints

1st	constraint makes sure that	each customer is served by exactly one warehouse.
2nd	constraint makes sure that	P warehouses are built.
3rd	constraint makes sure that	a customer is not served by an unopened warehouse.

Or, expressed as equations:

$$\sum_{j \in J} y_{ij} = 1$$

$$\sum_{j \in J} x_j = P$$

$$y_{ij} \le x_j \qquad i \in I \qquad j \in J$$

$$x_j \in \{0,1\} \qquad j \in J$$

$$y_{ij} \in \{0,1\} \qquad i \in I \qquad j \in J$$

The construction of an OPL model file (`.mod`) follows the same format exactly. The P-Median problem can be formulated in IBM ILOG OPL like this:

```
//Data
int P = ...;
{string} Customers = ...;
{string} Warehouses = ...;
int Demand[Customers] = ...;
float Distance[Customers][Warehouses] = ...;

//Variables
dvar boolean OpenWarehouse[Warehouses];
dvar boolean ShipToCustomer[Customers][Warehouses];

//Objective
minimize
  sum( c in Customers , w in Warehouses )
    Demand[c]*Distance[c][w]*ShipToCustomer[c][w];

//Constraints
subject to {
  forall( c in Customers )
    ctShip:
      sum( w in Warehouses )
        ShipToCustomer[c][w] == 1;

  ctOpen:
    sum( w in Warehouses )
      OpenWarehouse[w] == P;

  forall( c in Customers , w in Warehouses )
    ctShipOpen:
      ShipToCustomer[c][w] <= OpenWarehouse[w];
}
```

Notice that:

♦ the names of the customers and warehouses are specified as sets of strings in the data file. (That is what the notation `{string}` means.)

- it is also possible to use sets of integers as the labels for the customers and warehouses. You can also use ranges instead of sets. The demand and distance data remain the same, regardless of the format of the labels for customers and warehouses.
- the `...` (ellipsis) syntax means that the data is initialized externally, that is, from a data file (`pmedian.dat`).

```
P=2;
Customers={"Albert","Bob","Chris","Daniel"};
Warehouses={"Santa Clara","San Jose","Berkeley"};
Demand=[100,80,80,70];
Distance=
[[ 2 , 10 , 50 ],
 [ 2, 10, 52 ],
 [ 50, 60 , 3],
 [ 40 , 60 , 1]];
```

Two solving engines

After the model, data, and settings files are complete, use the **Run** button ▶ or the context menus in the OPL Projects Navigator to run your model.

The time it will take to solve a model naturally depends on the size and complexity of the model. Typical textbook problems like the P-Median problem usually solve very quickly. If the solver finds a feasible solution, it displays the solution in the **Solutions** tab of the Output Area. (See *The Main window*.) The solver will continue working until an optimal solution is found or until you click the **Abort** button.

OPL supports two solving engines:

♦ the CPLEX® engine for mathematical programming is used by default when you run your project if your model does not start with the statement `using CP;`. This is the case of the P-Median problem described in the *Modeling the P-Median problem with OPL*.

♦ the CP Optimizer engine for constraint programming is called if your model starts with the statement `using CP;`. You can write, edit and solve the model from the OPL IDE, from the oplrun command line tool, and from the APIs.

You will find more information on CP modeling and solving in the documentation set. In particular, *Constraint programming versus mathematical programming* in the *Language User's Manual* presents the differences between MP models and CP models.

Debugging and dealing with error messages

OPL checks for errors in the model and data files.

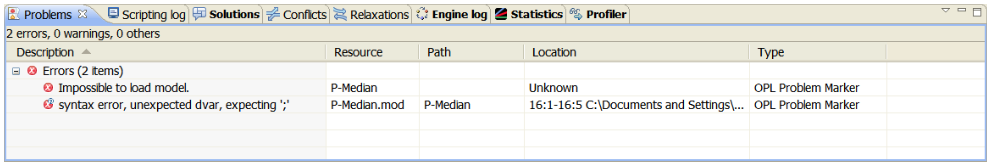
Syntax errors

Syntax and semantic errors are displayed dynamically in the Issues tab as you type.

For example, a common error is to forget to put a semicolon at the end of a statement. If you omit the semicolon at the end of the line

```
int P = ...;
```

the **Problems** tab displays the description, location, and source file of the error.



2 errors, 0 warnings, 0 others

Description	Resource	Path	Location	Type
Errors (2 items)				
Impossible to load model.	P-Median		Unknown	OPL Problem Marker
syntax error, unexpected dvar, expecting ';'	P-Median.mod	P-Median	16:1-16:5 C:\Documents and Settings\...	OPL Problem Marker

Generally, error messages will look similar to this example.

Solving errors

Immediately after you run your project, OPL checks for errors that prevent the solver from running. If such errors are found, one or more error messages will be displayed in the **Problems** tab. (See *The Main window* section.)

Displaying solutions

It is possible for you to view solutions while the solver is running as well as after it has finished. In addition to the **Solutions** tab of the Output Area, you can view a solution in tabular form through the **Problem Browser**. (See *The Main window*.) If your model expresses a MIP problem that generates feasible solutions, you can see the solution pool in the Problem Browser and further populate it with more nonoptimal solutions. (You can also see feasible solutions in the Solutions tab if certain Language settings are selected; see *After running a project* and Setting language options.)

You can see variable values in the Problem Browser, which also contains information about data structures, data values, labeled constraints and sensitivity data, as well as postprocessing data.

Summary: what you can do with the OPL IDE

The IBM® ILOG® OPL IDE is an integrated development environment (IDE) for mathematical programming, constraint programming, and combinatorial optimization applications in general. It is the graphical user interface (GUI) for the Optimization Programming Language and IBM ILOG Script for OPL, its scripting language.

With the IBM ILOG OPL IDE you can:

- Create and modify project files, as well as model and data, using the editing capabilities
- Create and modify settings files to apply language options, mathematical programming parameters and constraint programming parameters
- Execute a project
- Visualize OPL results in text or tabular form
- Search for relaxations of variables and constraints, and for conflicts between constraints in infeasible MP models
- Identify the time and memory consumed for the execution of a project
- Work with IBM ILOG Script for OPL, the scripting language
- Debug scripts using the debug facilities
- Generate a compiled model
- Generate external data files or internal data files to various formats
- Visualize the state of variables at some point during the search for a solution
- Connect to a database or to a spreadsheet to read and write data
- Set preferences for the appearance the IDE
- and carry out many other tasks

From problem solving to what-if scenarios: IBM ILOG ODM

Presents IBM® ILOG® Optimization Decision Manager, a solution for the development and deployment of optimization-based planning and scheduling applications.

In this section

ODM Overview

IBM® ILOG® OPL is integrated with a companion product called IBM ILOG Optimization Decision Manager (ODM). IBM ILOG ODM is both a tool for application development and a runtime environment for the distributed applications, and the combined product is a complete solution for the development and deployment of optimization-based desktop planning and scheduling applications.

In essence, you supply the mathematical model in OPL, and ODM supplies the GUI and the interactivity with your model that makes it easy to use for operations managers and planners. ODM is perfect for OR professionals who want to easily create and configure desktop solutions for their users in the OPL IDE, without the need for programming skills.

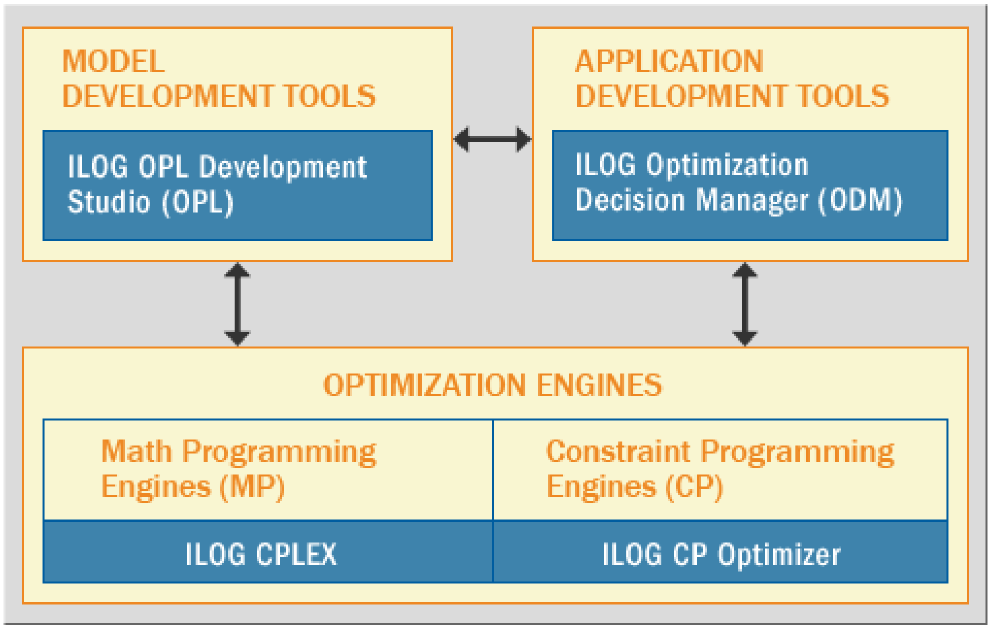
Desktop applications built with IBM ILOG ODM allow users to adjust assumptions, operating constraints and goals for planning and scheduling resources, and see the results in familiar business terms, providing extensive what-if analysis and scenario comparison features “out of the box.”

For more extensive corporation-wide applications, we provide another product, IBM ILOG ODM Enterprise, which allows you to build distributed applications (both remote execution and multi-user), and offers an extensive platform for customization using Java™ and IBM ILOG JViews.

How OPL and ODM integrate

IBM® provides a complete set of tools for building custom optimization-based decision support applications, which includes.

- **IBM!® ILOG® CPLEX®** – A mathematical programming engine that solves the full range of LP and MIP problems encountered in the real world.
- **IBM ILOG CP Optimizer** – A constraint programming engine that solves complex scheduling and routing problems.
- **IBM ILOG OPL** – A complete IDE for rapid development and deployment of optimization models.


MODEL DEVELOPMENT TOOLS
ILOG OPL Development Studio (OPL)
APPLICATION DEVELOPMENT TOOLS
ILOG Optimization Decision Manager (ODM)
OPTIMIZATION ENGINES
Math Programming Engines (MP)
Constraint Programming Engines (CP)
ILOG CPLEX
ILOG CP Optimizer

OPL, ODM, CPLEX and CP Optimizer

IBM makes optimization more widely accessible than ever before, because it offers such a wide range of capabilities across several fundamental dimensions, typically:

- **Supporting many types of optimization applications:** From off-line strategic planning applications through detailed scheduling to real-time operational applications.
- **Supporting the complete model development and application life-cycle:** Complete support for the application development process, from quick prototyping through model and application refinement, to application deployment and maintenance.
- **Supporting multiple personas:** OR and IT professionals, together with operations and business managers, can now collaborate in entirely new ways to rapidly generate custom decision-support applications.

Rapid development with tightly integrated OPL and ODM

Developing an application with IBM® ILOG® OPL and IBM ILOG ODM is very easy and productive.

The integration comes with a wizard that automatically generates an ODM application based on the structure of your OPL model.

- ♦ OPL data structures such as arrays and tuple sets are mapped to input data tables and graphical views in ODM. Because they are editable, users can then play out scenarios in ODM based on data changes.
- ♦ Mathematical constraints from your OPL model can be exposed as ODM *requirements* (soft constraints) with priorities, allowing a business user to make trade-offs between conflicting business requirements and alternative relaxations.
- ♦ The objectives of your mathematical model are mapped to ODM *goals*, which allow interactive goal programming and balancing between multiple objective criteria.
- ♦ Decision variables in the model are represented as solution views in ODM, and can be configured to show aggregate values and key performance indicators (KPIs), as well as providing exporting to Excel and integration with reporting tools.

The generated ODM application is configurable through editors inside OPL, and as the model evolves it can be extended to take new business requirements into account. The following figure shows how a chart view in ODM is configured in OPL.

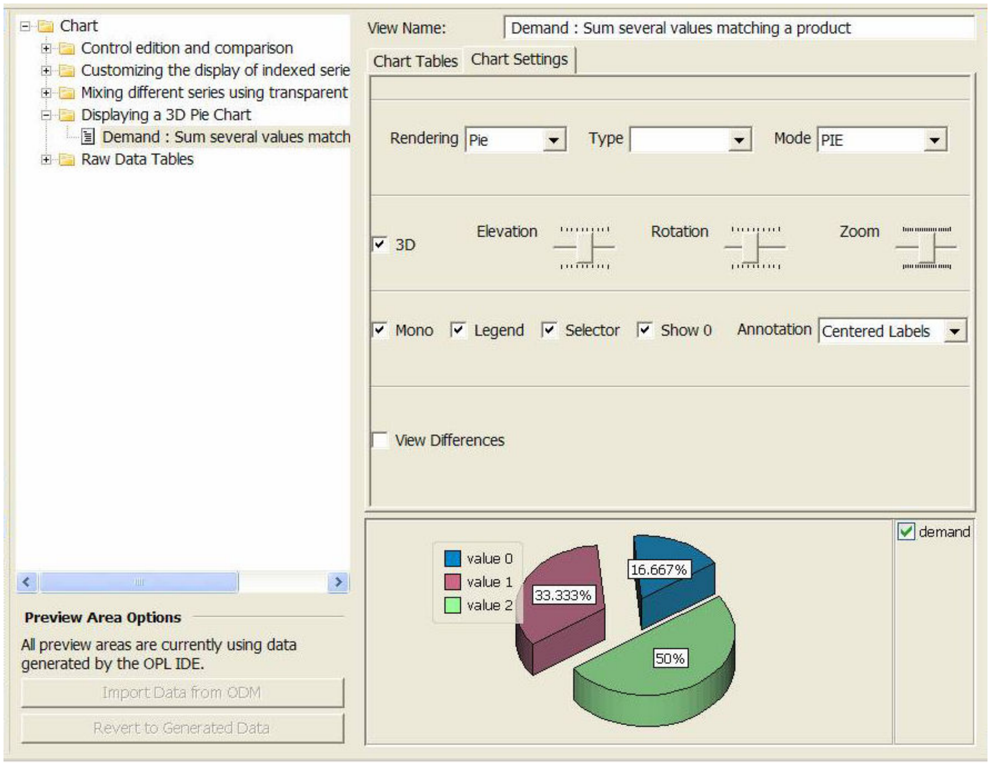


Chart
- Control edition and comparison
- Customizing the display of indexed serie
- Mixing different series using transparent
- Displaying a 3D Pie Chart
  - Demand : Sum several values match
- Raw Data Tables

View Name: Demand : Sum several values matching a product

Chart Tables | Chart Settings

Rendering: Pie | Type: | Mode: PIE

[✓] 3D | Elevation | Rotation | Zoom

[✓] Mono | [✓] Legend | [✓] Selector | [✓] Show 0 | Annotation: Centered Labels

[ ] View Differences

Preview Area Options

All preview areas are currently using data generated by the OPL IDE.

Import Data from ODM

Revert to Generated Data

Configuring an ODM chart view in OPL

Developing an application with IBM ILOG OPL and IBM ILOG ODM also allows business users to take part in the rapid prototyping and iterative development needed to strengthen definitions of requirements, refine models, perfect scenario parameters, and examine KPIs, solution views, and business goals.

Note: If you are reading this because you are a current OPL user but without access to ODM, please contact your IBM sales representative.

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