example, maximising the product titre does not necessarily lead to the best way of performing the process. Additionally, the complex interplay between the different factors driving the outcome of the process is underestimated in conventional approaches.

Further, conventionally, available knowledge about a process, which may come from theoretical assumptions and previous executions, is taken into consideration only in a rudimental manner, e.g. selecting *a priori* a value for a parameter or a model for the physical and biological dynamics involved in the process. For example, in the design of experiments (DoE), the shape (e.g. linear or quadratic) of the response of the process to the driving parameters is usually selected *a priori.*

Summary

According to an aspect, the present disclosure refers to a computer-implemented method of determining at least one recipe for a production process to produce a chemical, pharmaceutical and/or biotechnological product, wherein the production process is defined by a plurality of steps specified by recipe parameter(s) controlling an execution of the production process and a recipe comprises the plurality of steps defining the production process, the method comprising:

- retrieving:

-- one or more recipe template composites, wherein a recipe template composite comprises one or more recipe templates and a recipe template is a recipe in which at least one of the recipe parameter(s) specifying the plurality of steps is a variable recipe parameter being variable and having no predetermined value at the outset;

-- process evolution information that describes the time evolution of process variable(s) that describe a state of the production process, wherein the process evolution information comprises evolution parameter(s) and at least one of the evolution parameter(s) is a variable evolution parameter being variable and having no predetermined value at the outset;

-- a likelihood function for the evolution parameter(s), wherein the likelihood function provides a likelihood that value(s) for the evolution parameter(s) are feasible for the production process;

-- a mapping that maps the process variable(s) onto performance indicator(s);

-- a utility function for at least one of the performance indicator(s), wherein the utility function provides a desirability value associated to the performance indicator(s);

- selecting a recipe template composite and performing a first optimisation step comprising:

-- providing a set of input values for the at least one variable recipe parameter in the recipe template composite;

-- performing a second optimisation step providing a utility score;

-- repeating the second optimisation step for at least another set of input values, thereby obtaining a plurality of utility scores;

-- identifying the optimal utility score from the plurality of utility scores;

- if only one recipe template composite was retrieved, selecting the set of input values that yields the optimal utility score together with the one recipe template composite as the at least one recipe for the production process; or

- if more than one recipe template composite was retrieved:

-- repeating the first optimisation step for each recipe template composite, thereby obtaining a plurality of optimal utility scores;

-- identifying the best optimal utility score among the plurality of optimal utility scores;

-- selecting the recipe template composite and the set of input values that yield the best optimal utility score as the at least one recipe for the production process;

wherein:

- the second optimisation step comprises:

-- providing a set of likely values for the at least one variable evolution parameter based on the likelihood function;

-- performing a third optimisation step providing a utility tally;

-- if there is at least another set of likely values that is suitable, repeating the third optimisation step for the at least another set of likely values, thereby obtaining a plurality of utility tallies;

-- computing the utility score by weighting the utility tally(ies) by the likelihood function;

- the third optimisation step comprises:

-- performing a fourth optimisation step providing a utility value;

-- if a stochasticity flag is set, repeating the fourth optimisation step, thereby obtaining a plurality of utility values;

-- computing the utility tally as the utility value or by compounding the plurality of utility values;

- the fourth optimisation step comprises:

-- generating a simulation by simulating the execution of the production process using a recipe template in the recipe template composite with the set of input values for the at least one variable recipe parameter, the process evolution information and the set of likely values for the at least one variable evolution parameter;

-- if the recipe template composite comprises more than one recipe template, repeating the step of generating the simulation for each recipe template in the recipe template composite;

-- determining, from the one or more simulations, trajectory(ies) for the process variable(s), wherein a trajectory corresponds to a time-based profile of values recordable during the simulated execution of the production process;

-- computing the utility value by evaluating the utility function using the process variable(s) of the trajectory(ies) and the mapping.

According to an aspect, the present disclosure refers to a computer program product comprising computer-readable instructions, which, when loaded and executed on a computer system, cause the computer system to perform operations according to the method of the above aspect.

According to an aspect, the present disclosure refers to a computer system operable to determine at least one recipe for a production process to produce a chemical, pharmaceutical and/or biotechnological product, wherein the production process is defined by a plurality of steps specified by recipe parameter(s) controlling an execution of the production process and a recipe comprises the plurality of steps defining the production process, the computer system comprising:

- a retrieving module configured to retrieve:

-- one or more recipe template composites, wherein a recipe template composite comprises one or more recipe templates and a recipe template is a recipe in which at least one of the recipe parameter(s) specifying the plurality of steps is a variable recipe parameter being variable and having no predetermined value at the outset;

-- process evolution information that describes the time evolution of process variable(s) that describe a state of the production process, wherein the process evolution information comprises evolution parameter(s) and at least one of the evolution

parameter(s) is a variable evolution parameter being variable and having no predetermined value at the outset;

-- a likelihood function for the evolution parameter(s), wherein the likelihood function provides a likelihood that value(s) for the evolution parameter(s) are feasible for the production process;

-- a mapping that maps the process variable(s) onto performance indicator(s);

-- a utility function for at least one of the performance indicator(s), wherein the utility function provides a desirability value associated to the performance indicator(s);

- a computing module configured to select a recipe template composite and perform a first optimisation step comprising:

-- providing a set of input values for the at least one variable recipe parameter in the recipe template composite;

-- performing a second optimisation step providing a utility score;

-- repeating the second optimisation step for at least another set of input values, thereby obtaining a plurality of utility scores;

-- identifying the optimal utility score from the plurality of utility scores;

wherein the computing module is further configured, if only one recipe template composite was retrieved, to select the set of input values that yields the optimal utility score together with the one recipe template composite as the at least one recipe for the production process;

or the computing module is further configured, if more than one recipe template composite was retrieved, to:

- repeat the first optimisation step for each recipe template composite, thereby obtaining a plurality of optimal utility scores;

- identify the best optimal utility score among the plurality of optimal utility scores;

- select the recipe template composite and the set of input values that yield the best optimal utility score as the at least one recipe for the production process;

and wherein:

- the second optimisation step comprises:

-- providing a set of likely values for the at least one variable evolution parameter based on the likelihood function;

-- performing a third optimisation step providing a utility tally;

-- if there is at least another set of likely values that is suitable, repeating the third optimisation step for the at least another set of likely values, thereby obtaining a plurality of utility tallies;

-- computing the utility score by weighting the utility tally(ies) by the likelihood function;

- the third optimisation step comprises:

-- performing a fourth optimisation step providing a utility value;

-- if a stochasticity flag is set, repeating the fourth optimisation step, thereby obtaining a plurality of utility values;

-- computing the utility tally as the utility value or by compounding the plurality of utility values;

- the fourth optimisation step comprises:

-- generating a simulation by simulating the execution of the production process using a recipe template in the recipe template composite with the set of input values for the at least one variable recipe parameter, the process evolution information and the set of likely values for the at least one variable evolution parameter;

-- if the recipe template composite comprises more than one recipe template, repeating the step of generating the simulation for each recipe template in the recipe template composite;

-- determining, from the one or more simulations, trajectory(ies) for the process variable(s), wherein a trajectory corresponds to a time-based profile of values recordable during the simulated execution of the production process;

-- computing the utility value by evaluating the utility function using the process variable(s) of the trajectory(ies) and the mapping.

It is an objective of the disclosure to optimise a process for the production of chemical, pharmaceutical and/or biotechnological products, wherein the process is regarded in its entirety and complexity. In particular, it is an objective to account accurately for the plurality of factors affecting the execution and possible outcomes of the process and to duly consider the plural aspects characterizing the performance of the process. In this context, it is also an objective to integrate effectively available knowledge about the process in the optimisation procedure.

The achievement of these objectives in accordance with the disclosure is set out in the above aspects. Further developments of the invention are disclosed herein.

According to one example, a computer-implemented method of determining at least one recipe for a production process to produce a chemical, pharmaceutical and/or biotechnological product is provided. In particular, the determined recipe(s) may be the optimal recipe(s) in the sense that the production process is optimised in terms of a utility function, as will be explained below.

Examples of processes according to the present application are industrial processes, particularly biopharmaceutical processes. Other examples include research and development processes or scientific research.

As mentioned with reference to the features of the utility function above, the output of the utility function depends indirectly on the values for the evolution parameters. In this case, the values for the evolution parameters are associated with a given clone. Hence, the output of the utility function will indirectly depend on the clone chosen at scale A.

Therefore, numerical optimisation methods may be used to find the clone at scale A that optimises the output of the utility function at scale B.

According to another example , a computer program product is provided. The computer program product comprises computer readable instructions, which, when loaded and executed on a computer system, cause the computer system to perform operations as described above. The computer program product may be tangibly embodied in a computer readable medium.

Yet another example relates to a computer system operable to determine at least one recipe for a production process to produce a chemical, pharmaceutical and/or biotechnological product, wherein the production process is defined by a plurality of steps specified by recipe parameter(s) controlling an execution of the production process and a recipe comprises the plurality of steps defining the production process. The computer system comprises:

- a retrieving module configured to retrieve:

-- one or more recipe template composites, wherein a recipe template composite comprises one or more recipe templates and a recipe template is a recipe in which at least one of the recipe parameter(s) specifying the plurality of steps is a variable recipe parameter being variable and having no predetermined value at the outset;

-- process evolution information that describes the time evolution of process variable(s) that describe a state of the production process, wherein the process evolution information comprises evolution parameter(s) and at least one of the evolution parameter(s) is a variable evolution parameter being variable and having no predetermined value at the outset;

-- a likelihood function for the evolution parameter(s), wherein the likelihood function provides a likelihood that value(s) for the evolution parameter(s) are feasible for the production process;

-- performing a fourth optimisation step providing a utility value;

-- if a stochasticity flag is set, repeating the fourth optimisation step, thereby obtaining a plurality of utility values;

-- computing the utility tally as the utility value or by compounding the plurality of utility values;

- the fourth optimisation step comprises:

-- generating a simulation by simulating the execution of the production process using a recipe template in the recipe template composite with the set of input values for the at least one variable recipe parameter, the process evolution information and the set of likely values for the at least one variable evolution parameter;

-- if the recipe template composite comprises more than one recipe template, repeating the step of generating the simulation for each recipe template in the recipe template composite;

-- determining, from the one or more simulations, trajectory(ies) for the process variable(s), wherein a trajectory corresponds to a time-based profile of values recordable during the simulated execution of the production process;

-- computing a utility value by evaluating the utility function using the process variable(s) of the trajectory(ies) and the mapping.

In other words, the computer system is operable to perform a method according to the example discussed above.

The computer system may particularly comprise a memory and a processor to operate the modules. The retrieving module and the computing module may be separate entities or may at least partly overlap with each other.

Further, the computer system may be configured to interface with a control system via a network, shared disk, or database system, wherein the control system controls the execution of the production process in the real world. The interface may particularly allow transfer of data and/or commands. In some examples, the computer system may coincide with the control system.

To summarize, the method, the product and the system discussed above enable the determination of an optimal recipe for a production process, wherein the recipe can be