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- (54) Benævnelse: **FREM GANGSMÅDE TIL AT STYRE KØRETØJER I TILFÆLDE AF EN KONFLIKTSITUATION OG
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**EP-A1- 1 764 280
CN-B- 103 481 918
US-A- 4 122 523**

DESCRIPTION

Background of the invention

[0001] The invention concerns a method for controlling vehicles, in particular rail bound vehicles, in case of a conflict situation wherein an optimized solution is applied, the method comprising the following steps:

1. (a) determination of an actual operation state of the vehicles and/or of planned routes for said vehicles;
2. (b) classification of the conflict situation by assigning the actual operation state to a conflict class thereby determining an action space in dependence of the conflict class to which the actual operation state has been assigned, wherein the action space comprises allowed measures.

[0002] A method for resolving conflicts in a track bound transportation system is known from EP 1 500 567 A1.

[0003] During operation of a transportation system, in particular with rail bound vehicles, conflict situations may occur, e.g. due to non-working switches, blocked tracks, defect trains, etc. Conflict situations have to be solved as quickly as possible in order to continue the operation of a transportation system. In order to solve an original conflict situation, suitable measures are applied. Yet, by applying such measures subsequent conflicts may occur. A conflict situation is supposed to be solved if the original conflict all subsequent conflicts are solved. Thus solving a conflict includes applying measures in an ordered sequence (= solution)

[0004] According to the method known from EP 1 500 567 A1 first an empirical base is created by determining and simulating the complete solution space (all possible combination of all measures). The measures are assigned to conflict classes. An actual conflict situation is assigned to a conflict class. The relevant measures (action space) for the corresponding conflict class are looked up in the empirical basis and are combined to solutions wherein a solution tree is worked through. The solutions of the solution tree are simulated and rated. Although the known method only takes into account measures which are assigned to the relevant conflict class of the actual conflict situation, the computing time is still enormous since a multitude of combinations of measures have to be simulated in order to find a good solution.

[0005] EP 1 764 280 A1 discloses a method of operating a freight railway, comprising the steps of determining a movement plan by which the trains move along a layout, by evaluating the effects of track parameters on the movement of the trains. The method further comprises controlling said trains to move along the layout in accordance with said determined movement plan. The method known from EP 1 764 280 A1 requires much computing time and power.

[0006] US 4 122 523 A discloses a route conflict analysis system for control of railroads. An intended path of travel of various trains is analyzed to determine the existence of any conflicts. When one or more conflicts are detected, the system analyzes various options to resolve the conflict with a minimum disruption to the system based on predetermined constraints. The analysis proceeds on the basis of a heuristic search for conflict resolution. Each intermediate conflict resolution is examined and a cost is assigned to the intermediate conflict resolutions. If all conflicts within a group can be resolved, the problem has been successfully resolved.

Object of the invention

[0007] It is therefore an object of the invention to provide a method for controlling vehicles in case of a conflict situation which enables to find a suitable solution which solves the original conflict and all subsequent conflicts automatically with reduced time effort and compliance to the domain ruleset.

Description of the invention

[0008] This object is solved by a method according to claim 1, a decision support system according to claim 8 and a computer program according to claim 9.

[0009] The method according to the invention comprises the following steps:

(c) searching a knowledge base comprising rated solutions which are assigned to an operation state equal or similar to the actual operation state, wherein the rated solutions have been found to work well for a special operation state and comprise expert feedback;
in case one or more rated solutions are found which are assigned to an operation state which is similar to the actual operation state:

(d) selection of at least one rated solution from the knowledge base, wherein the at least one selected solution exclusively comprises measures of the action space;

(e) optimization of the at least one selected solution applied to the actual operation state using different optimization targets, wherein for each optimization target a separate simulation is executed,, wherein the optimization uses a genetic algorithm and results in an optimized solution, wherein the optimized solution is rated by a dispatcher.

(f) carrying out the optimized solution.

[0010] In case a rated solution is found, which is assigned to an operation state equal to the actual operation state, said solution is selected, proofed for conflicts by a simulation and

applied.

[0011] A **problem domain** is the field of application of the method e.g. maintenance, schedule, etc.

[0012] An **operation state** describes the traffic situation of a predetermined vehicle or status of a planned route (in case the operation state can be assigned to a conflict class the operation state is a conflict situation). Classification of the actual operation state is carried out by a classifier unit, which assigns the actual operation state to a corresponding conflict class.

[0013] A **solution space** comprises all possible measures for the respective problem domain. Due to the classification the solution space can be reduced to an **action space** by applying domain rules stored in a classifier unit (inference engine). The action space comprises suitable measures according to the conflict class to which the actual operation state has been assigned. Hence the action space is a reduced solution space. The measures and conflict classes are defined in advance and may differ from one country to another.

[0014] A **Solution** can comprise a single measure or multiple measures, in particular a series of measures, wherein the single measure or the multiple measures solve the conflict situation including subsequent conflicts.

[0015] The **knowledge base** comprises **rated solutions**, i.e. solutions which have been found to work well for a special operation state (expert feedback). Preferably a fitness factor is assigned to the rated solutions. Selection of at least one rated solution from the knowledge base is carried out by a seeder unit. The knowledge base is preferably developed during course of the inventive method (self-learning mechanism).

[0016] The selected rated solution is then optimized by means of a **solver unit** resulting in the optimized solution, which is proofed by a rule-based simulation according to the domain.

[0017] The inventive method supports decision making concerning choosing solutions in order to solve conflicts. The required time effort is reduced by combining deterministic method steps (classification, applying domain rules) with a heuristic approach (genetic algorithm). Automatically computed solutions are obtained, in particular for trains and infrastructure conflicts according to rescheduling and planning train schedules regarding specific railway operational rules, thus benefitting of both heuristic and deterministic methods.

[0018] The advantage of combining deterministic method steps with a heuristic approach compared to pure deterministically approach is that an optimized solution can be found with less time, because it is not fully determined by all possible parameter values and all conditions of the solution space. Moreover the self-learning effect of a genetic algorithm using continuous quality reinforcement by a solution ranking mechanism leads to find a good solution in less time.

[0019] The advantage of combining deterministic method steps with a heuristic approach compared to pure heuristically approach is that the inherent randomness of optimized solutions is drilled to being more predictable and comprehensible, because it follows a predefined domain ruleset additionally.

[0020] In contrast to the state of the art the inventive method does not need to calculate complete solution spaces, thereby reducing time effort.

[0021] In case no rated solution is found, which is assigned to the actual operation state or an operation state which is similar to the actual operation state, the following steps are preferably carried out:

(d') selection of possible measures from a solution space determined by the classification of the operation state;

(e') optimization of a combination of the selected possible measures applied to the actual operation state, wherein the optimization uses a genetic algorithm and results in an optimized solution;

(f) applying the optimized solution.

[0022] In this case no rated solutions are available. Thus solutions are created by selecting possible measures from the solution space. The possible measures are combined to a solution which has to be optimized by an automatic calculation of the genetic algorithm.

[0023] If the actual operation state is not equal to an operational state for which rated solutions are stored within the knowledge base, the selected (rated or non-rated) solution cannot be applied directly but has to be modified, i.e. parameters which do not fit to the actual operation state have to be changed. Parameters which are varied during an optimization process are called optimization parameters.

[0024] In a highly preferred variant of the inventive method optimization of step (e) and (e') respectively comprises:

1. (i) variation of at least one parameter of the selected solution by using the genetic algorithm resulting in a randomized solution;
2. (ii) simulation of the randomized solution by applying domain rules by means of the simulator unit;
3. (iii) ranking of the randomized solution, in particular by assigning a fitness factor to the randomized solution;
4. (iv) repetition of steps (i) - (iii) for different parameters.

[0025] First a genetic algorithm is applied, i.e. the optimization parameters are varied heuristically (random mutation). The solution for the varied parameter(s) is called "randomized solution". The simulation is carried out deterministically by applying domain rules. The following ranking is carried out e.g. by assigning a fitness factor to each randomized solution.

[0026] Variation and simulation/ranking is repeated a predetermined number of times, in particular several thousand times. The ranking of each variation does influence the ongoing iterations to increase the quality of the solution (reinforcement learning). Finally one of the randomized solutions, in particular the randomized solution with the best fitness factor, is selected to be carried out/applied (optimized solution).

[0027] In case the actual operation state is not equal but only similar to an operation state for which rated solutions are stored within the knowledge base (e.g. due to different numbers of closed tracks) the selected rated solution is used as a starting point for the optimization process.

[0028] In case the actual operation state does not match any operation state for which rated solutions are stored within the knowledge base the actual operation state without rated solutions is used for the optimization process.

[0029] In order to improve the knowledge base, it is preferred that the optimized solution (in particular including the corresponding ranking) is stored in the knowledge base. Thus the knowledge is provided for a self-learning system.

[0030] In a preferred variant each conflict class comprises class definitions and the actual operation state comprises state features and that in step (b) the actual operation state is assigned to the conflict class with the closest match between class definitions and state features of the actual operation state. **Class definitions** are features, which have to be fulfilled by an operation state in order to get assigned to the respective conflict class, e.g. blocked track, slow zone, power shut down, train/infrastructure conflicts, time conflict. The classifier unit which compares the actual operation state with class definitions and assigns the actual operation state to a corresponding conflict class.

[0031] It is preferred that the class definitions are weighted, and that in step (b) the actual operation state is assigned to the conflict class with the highest weight score. A weighting factor is assigned to each class definition. The values of the weighting factors of class definitions which correspond to state features are added. The actual operation state is assigned to the conflict class with the highest sum of weighting factors.

[0032] According to the invention step e) is carried out using different optimization targets. A solution can be optimized with respect to different targets. e.g. minimal delay, minimal number of trains to be rerouted, best energy efficiency...). For each target a separate simulation is executed. Therefore the varied solutions may be rated differently in dependence of the optimization target.

[0033] In case a rated solution is found, which is assigned to the actual operation state, that said solution is selected and carried out. I.e. in case the actual operation state is equal to an operation state for which a rated solution is stored within the knowledge base, the respective rated solution is selected, proofed by the conflict simulation and carried out. I.e. no optimization is necessary provided that at least one simulation has been executed and has confirmed that the solution is free of conflicts.

[0034] Solutions which are stored in the knowledge base are rated. The rating may comprise for example the fitness factors which have been assigned to the solution during the ranking by means of the ranker unit.

[0035] Additionally or alternatively the optimized solution may be statistically rated. E.g. the rating of a solution is higher the more often said solution has been selected or the rating of a solution is higher the better the assigned fitness factor is.

[0036] According to the invention, the optimized solution is rated by a dispatcher. A more individual rating is possible taking into account various criteria. Also other criteria for rating are possible.

[0037] The invention also concerns a decision support system comprising the features of claim 8.

[0038] The action space comprises types of measures which are allowed for the actual operation state.

[0039] During optimization the genetic algorithm is applied to selected solution or the combination of selected possible measures. The rated solutions selected by the seeder unit are used as advanced starting points with a reduced action spaces.

[0040] The inventive decision support system does not require special hardware or hardware distribution. The above listed units of the inventive decision support system are software-units which can be implemented with standard laptops and PCs. Due to a component based architecture the units of the inventive decision support system may run within one hardware unit or may be distributed to several hardware units.

[0041] The invention further concerns a computer program product comprising instructions to cause the before described system for executing the steps of the method as described before. The computer program product comprises the above described decision support system.

[0042] Further advantages can be extracted from the description and the enclosed drawing.

[0043] The embodiments mentioned are not to be understood as exhaustive enumeration but rather have exemplary character for the description of the invention.

Drawings

[0044] The invention is shown in the drawing.

FIG. 1

shows a diagram of a conflict resolution system according to the invention.

FIG. 2

shows a flow diagram according to the inventive method.

FIG. 3

shows a flow diagram concerning knowledge seeding for different scenarios.

[0045] The structure of the inventive conflict resolution system is shown in **FIG. 1**. The method steps of the inventive method are shown in **FIG. 2**.

[0046] A classifier unit **1** receives the actual operation state of one or more vehicle(s) e.g. from an external system. First the actual operation state is analyzed by a simulator unit **2** to identify conflicts and problems that are used for conflict classification by the classifier unit **1**.

[0047] Class definitions are stored within the classifier unit. The classifier unit compares the problem statistic of the operation state with class definitions and assigns the actual operation state to a conflict class with the best fitting class definitions, wherein different class definitions may have different weight factors.

[0048] Information concerning the actual operation state and conflict class is sent from the classifier unit **1** to a seeder unit **3**. Further the seeder unit **3** has access to the knowledgebase **4**. The seeder unit **3** searches the knowledge base **4** for rated solutions which comply with the previously determined action space and which are assigned to an operation state which is equal or similar to the actual operation state.

[0049] **FIG. 3** shows three possible scenarios for the following knowledge seeding: If the knowledge base **4** comprises a rated solution which is assigned to an operation state equal to the actual operation state, the corresponding rated solution is selected, proofed by the conflict simulation and applied.

[0050] If the knowledge base **4** does not comprise any rated solution which is assigned to an operation state which is equal or similar to the actual operation state, a combination of selected possible measures applied the actual operation state is optimized with the predefined action space. The optimized solution is carried out.

[0051] If the knowledge base **4** comprises one or more rated solution(s) which is/are assigned to an operation state similar to the actual operation state, the one or more of the

corresponding rated solution(s) is/are selected and optimized, wherein the rated solution(s) is/are used as starting point for the optimization, as shown in FIG. 2.

[0052] The optimization process is carried out by a solver unit 5, the simulator unit 2 and a ranker unit 6. By using a rated solution from the knowledge base 4 as starting point computing time and required computing power can be reduced. The solver unit 5 determines parameter to be varied in order to find an optimized solution, i.e. the parameters are varied mutually. Variation of these parameters is done by applying a genetic algorithm. Randomized solutions are obtained herewith. The randomized solutions are simulated by applying domain rules by means of the simulator unit 2 resulting in a polished solution, i.e. the simulator unit 2 ensures that the optimized solution complies with the stored domain rules, which helps to detect and prevent conflicts (see FIG. 2). A ranking is carried out by means of the ranker unit by applying a ranking pattern, e.g. the number of conflicts which are still left in the solution, the number of trains which reach their destination in time, The ranking is done in respect of an optimization target by applying a fitness factor to each polished solution. Different optimization targets can be used which may result in different fitness factors for the same randomized solution. The randomized solution with the best fitness factor for a selected optimization target is selected as optimized solution to be carried out.

[0053] The optimized solution (including its fitness factor(s)) is stored in the knowledge base 4 in order to provide a self-learning system.

[0054] The inventive method provides a heuristic optimization of solutions by means of genetic algorithm taking into consideration domain rules thereby providing good solutions with low time effort.

[0055] In the following table an example of a conflict situation and the elements/information used for applying the inventive method are shown:

actual operation state	two trains A + B cannot enter track section due to a construction site
relevant conflict class	conflicted track section
class definitions or relevant conflict class	• blocked track section
	• non-electrified track section
	• track allocation conflict (train/train)
	• incompatibility conflict (infrastructure/train)
problem domain	Train cannot reach its destination
action space	• change train path
	• adapt train speed
	• extend train stop
	• insert additional train stop
operation state of rated measure of knowledge base	two trains A + B cannot enter track section of a track X due to a defective switch

rated measure	reduction of speed of the trains A+B and change train path to another track Y
fix parameter	number of trains
parameter to be varied	speed of trains A + B
	train path of trains A + B
optimization target	• minimal train delay
	• maximal train throughput
	• minimal allocation conflicts
	• train destination was reached

List of reference signs

[0056]

- 1
- classifier unit
- 2
- simulator unit
- 3
- seeder unit
- 4
- knowledgebase
- 5
- solver unit
- 6
- ranker unit

REFERENCES CITED IN THE DESCRIPTION

This list of references cited by the applicant is for the reader's convenience only. It does not form part of the European patent document. Even though great care has been taken in compiling the references, errors or omissions cannot be excluded and the EPO disclaims all liability in this regard.

Patent documents cited in the description

- EP1500567A1 [0002] [0004]
- EP1764280A1 [0005] [0005]
- US4122523A [0006]

Patentkrav

1. Fremgangsmåde til at styre køretøjer, i særdeleshed skinneførte køretøjer, i tilfælde af en konfliktsituation, hvilken fremgangsmåde omfatter de følgende trin:

- 5 (a) bestemmelse af en aktuel driftstilstand af køretøjerne og/eller af planlagte ruter for nævnte køretøjer;
- (b) klassificering af konfliktsituationen ved at tildele den aktuelle driftstilstand til en konfliktklasse for derved at bestemme et aktionsrum afhængigt af konfliktklassen til hvilken den aktuelle driftstilstand er blevet tildelt, hvor aktionsrummet omfatter tilladte foranstaltninger;
- 10 (c) søgning i en vidensbank omfattende vurderede løsninger der er tildelt til en driftstilstand lig med eller lignende den aktuelle driftstilstand hvor de vurderede løsninger er vurderet at fungere godt for en speciel driftstilstand og omfatter ekspertfeedback;
- 15 i tilfælde at en eller flere vurderede løsninger findes, der er tildelt til en driftstilstand, som er lignende den aktuelle driftstilstand:
- (d) udvælgelse af mindst en vurderet løsning fra vidensbanken, hvor den mindst ene valgte løsning udelukkende omfatter foranstaltninger af aktionsrummet;
- 20 (e) optimering af den mindst ene valgte løsning anvendt på den aktuelle driftstilstand under anvendelse af forskellige optimeringsmål, hvor for hvert optimeringsmål en separat simulering eksekveres, hvor optimeringen bruger en genetisk algoritme og resulterer i en optimeret løsning, hvor den optimerede løsning vurderes af en kørselsleder;
- (f) udførelse af den optimerede løsning;
- 25 i tilfælde at en vurderet løsning findes, som er tildelt til en driftstilstand lig med den aktuelle driftstilstand, nævnte løsning vælges, sikres for konflikter af en simulering og anvendes.

2. Fremgangsmåde ifølge krav 1, **kendetegnet ved, at** i tilfælde at ingen
30 vurderet løsning findes, som er tildelt til den aktuelle driftstilstand eller en driftstilstand, som er lignende den aktuelle driftstilstand, de følgende trin udføres:

(d') udvælgelse af mulige foranstaltninger fra et løsningsrum bestemt af klassificeringen af driftstilstanden;

5 (e') optimering af en kombination af de valgte mulige foranstaltninger anvendt på den aktuelle driftstilstand, hvor optimeringen bruger en genetisk algoritme og resulterer i en optimeret løsning;

(f) anvendelse af den optimerede løsning.

3. Fremgangsmåde ifølge et hvilket som helst af de foregående krav, **kendetegnet ved, at** optimering omfatter:

10 (i) variation af mindst et parameter af den valgte løsning varieres ved anvendelse af den genetiske algoritme der resulterer i en randomiseret løsning;

(ii) simulering af den randomiserede løsning ved anvendelse af domænereregler ved hjælp af simulatorenheden;

15 (iii) rangering af den randomiserede løsning, i særdeleshed ved tildeling af en egnethedsfaktor til den randomiserede løsning;

(iv) gentagelse af trinnene (i) - (iii) for forskellige parametre.

4. Fremgangsmåde ifølge et hvilket som helst af de foregående krav, **kendetegnet ved, at** den optimerede løsning lagres i vidensbanken.

5. Fremgangsmåde ifølge et hvilket som helst af de foregående krav, **kendetegnet ved, at** hver konfliktklasse omfatter klassedefinitioner og den aktuelle driftstilstand omfatter tilstandsegenskaber og at i trin (b) den aktuelle driftstilstand tildeles til konfliktklassen med det nærmeste match mellem

25 klassedefinitioner og tilstandsegenskaber af den aktuelle driftstilstand.

6. Fremgangsmåde ifølge krav 5, **kendetegnet ved, at** at klassedefinitionerne vægtes, og at i trin (b) den aktuelle driftstilstand tildeles til konfliktklassen med

30 højeste vægtscore.

7. Fremgangsmåde ifølge et af kravene 1 til 5, **kendetegnet ved, at** løsningerne i vidensbanken statistisk vurderes.

8. Beslutningsstøttesystem konfigureret til at eksekvere fremgangsmåden ifølge 5 et hvilket som helst af de foregående krav omfattende:

en lagringsenhed konfigureret til at lagre en vidensbank (4) omfattende vurderede løsninger der er tildelt til en driftstilstand lig med eller lignende den aktuelle driftstilstand og som er fundet at fungere godt for en speciel driftstilstand og omfatter ekspertfeedback,

10 organ konfigureret til at bestemme en aktuel driftstilstand af køretøjerne og/eller af planlagte ruter for nævnte køretøjer,

en klassificeringsenhed (1) konfigureret til at klassificere konfliktsituationen ved at tildele en aktuel driftstilstand til en konfliktklasse for derved at bestemme et aktionsrum afhængigt af konfliktklassen til hvilken den 15 aktuelle driftstilstand er blevet tildelt, hvor aktionsrummet omfatter tilladte foranstaltninger,

en sorteringsenhed (3) konfigureret til at vælge vurderede løsninger af vidensbanken, hvor den mindst ene valgte løsning udelukkende omfatter foranstaltninger af aktionsrummet,

20 en løsningsenhed (5) konfigureret til at udføre parametervariation ved anvendelse af en genetisk algoritme på baggrund af det tildelte aktionsrum,

en simulatorenhed (2) konfigureret til at lagre domæneregler der understøtter detektionen og/eller forebyggelsen af konflikter under en 25 simulering af den aktuelle driftstilstand,

organ konfigureret til at optimere den mindst ene valgte løsning anvendt på den aktuelle driftstilstand under anvendelse af forskellige optimeringsmål, hvor for hvert optimeringsmål en separat simulering eksekveres, hvor optimeringen bruger en genetisk algoritme og resulterer i 30 en optimeret løsning, hvor den optimerede løsning vurderes af en kørselsleder,

en rangeringsenhed (6) konfigureret til at rangere de optimerede løsninger ved anvendelse af forskelligt rangeringsmønster, og

5 organ konfigureret til at udføre den optimerede løsning; hvor i tilfælde en vurderet løsning findes, som er tildelt til en driftstilstand lig med den aktuelle driftstilstand, nævnte løsning vælges, sikres for konflikter af en
10 simulering og anvendes.

9. Computerprogramprodukt omfattende instruktioner til at forårsage systemet ifølge krav 8 til at eksekvere trinnene af fremgangsmåden ifølge et hvilket som
10 helst af kravene 1 til 7.

DRAWINGS

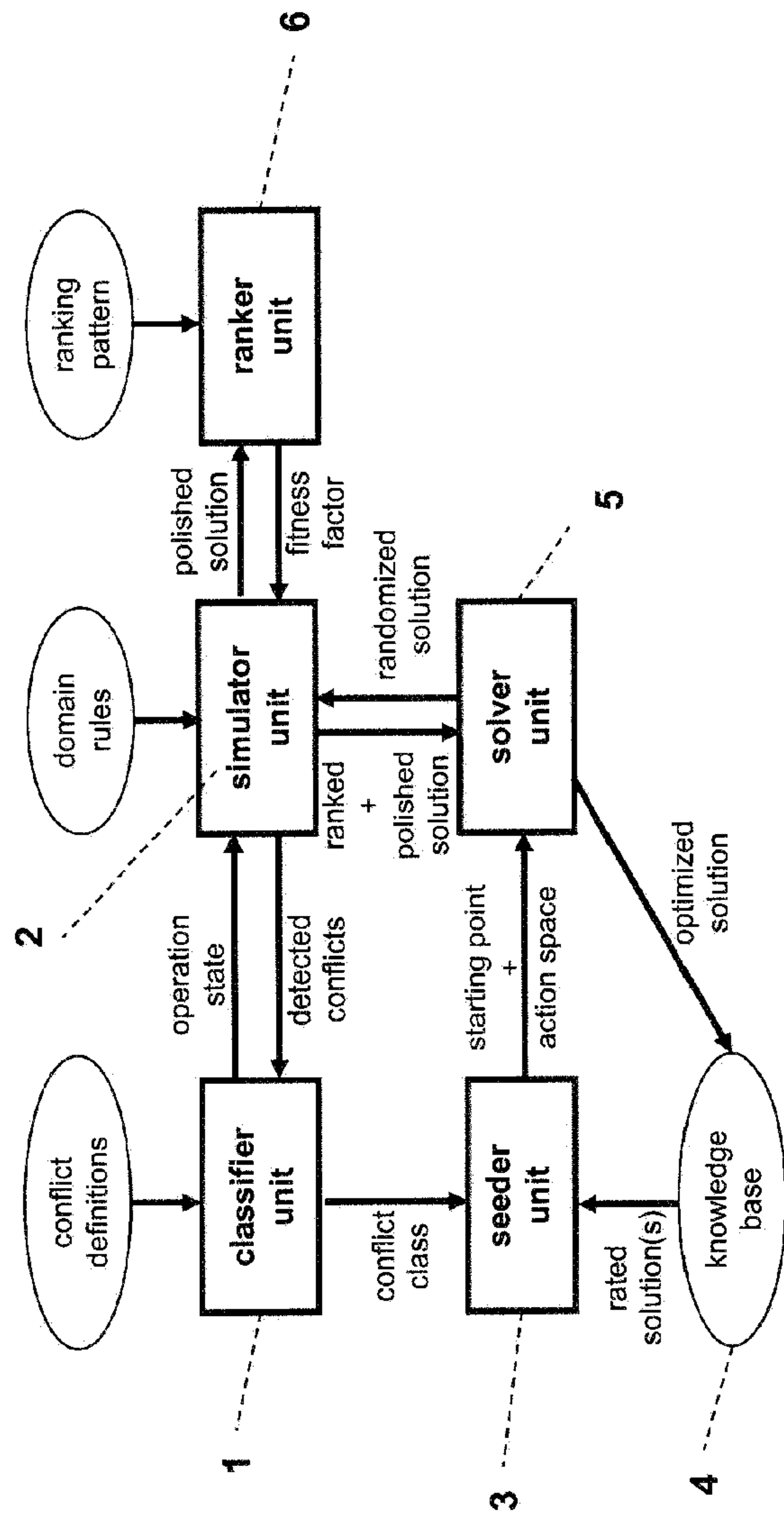


Fig. 1

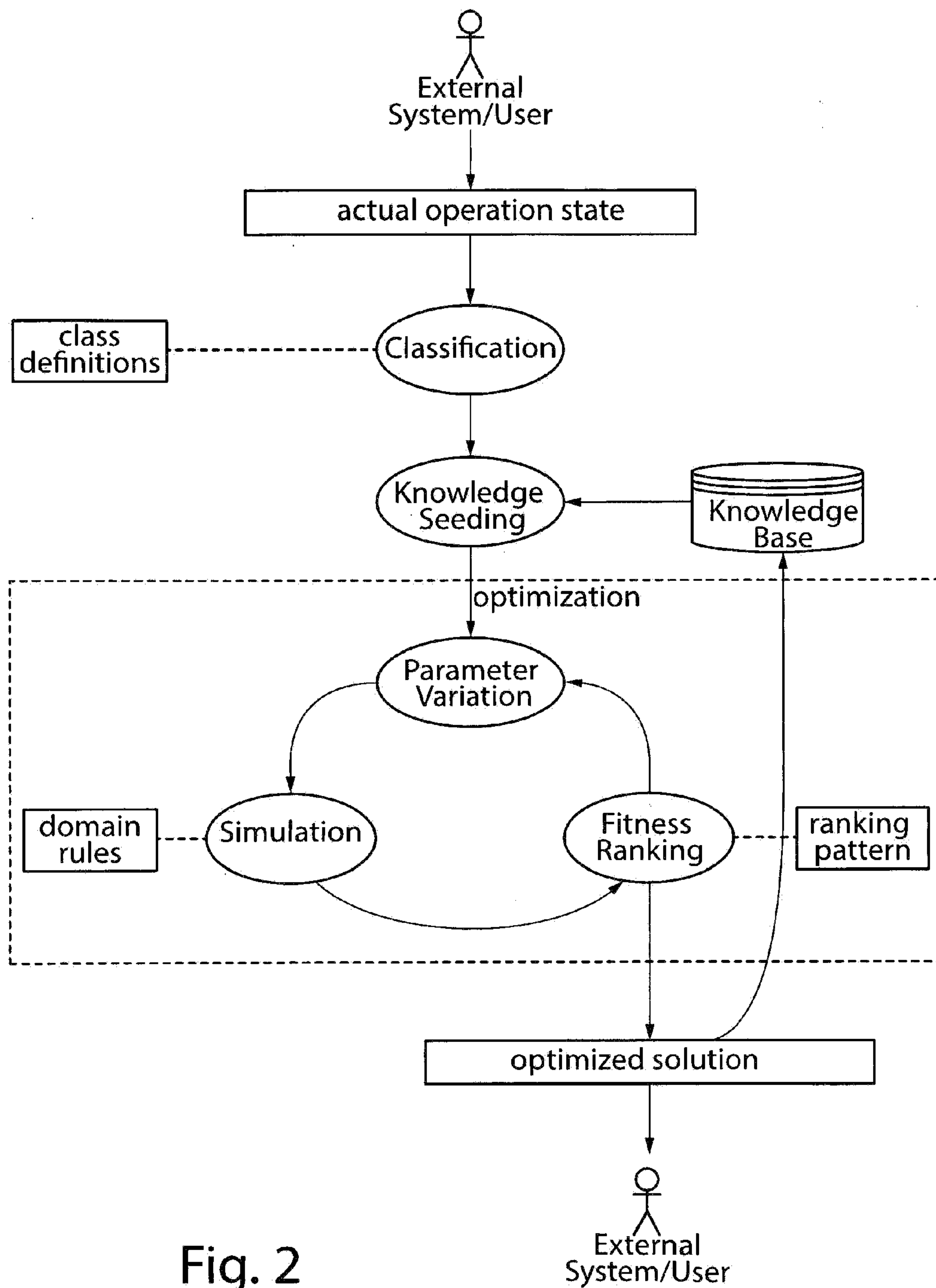


Fig. 2

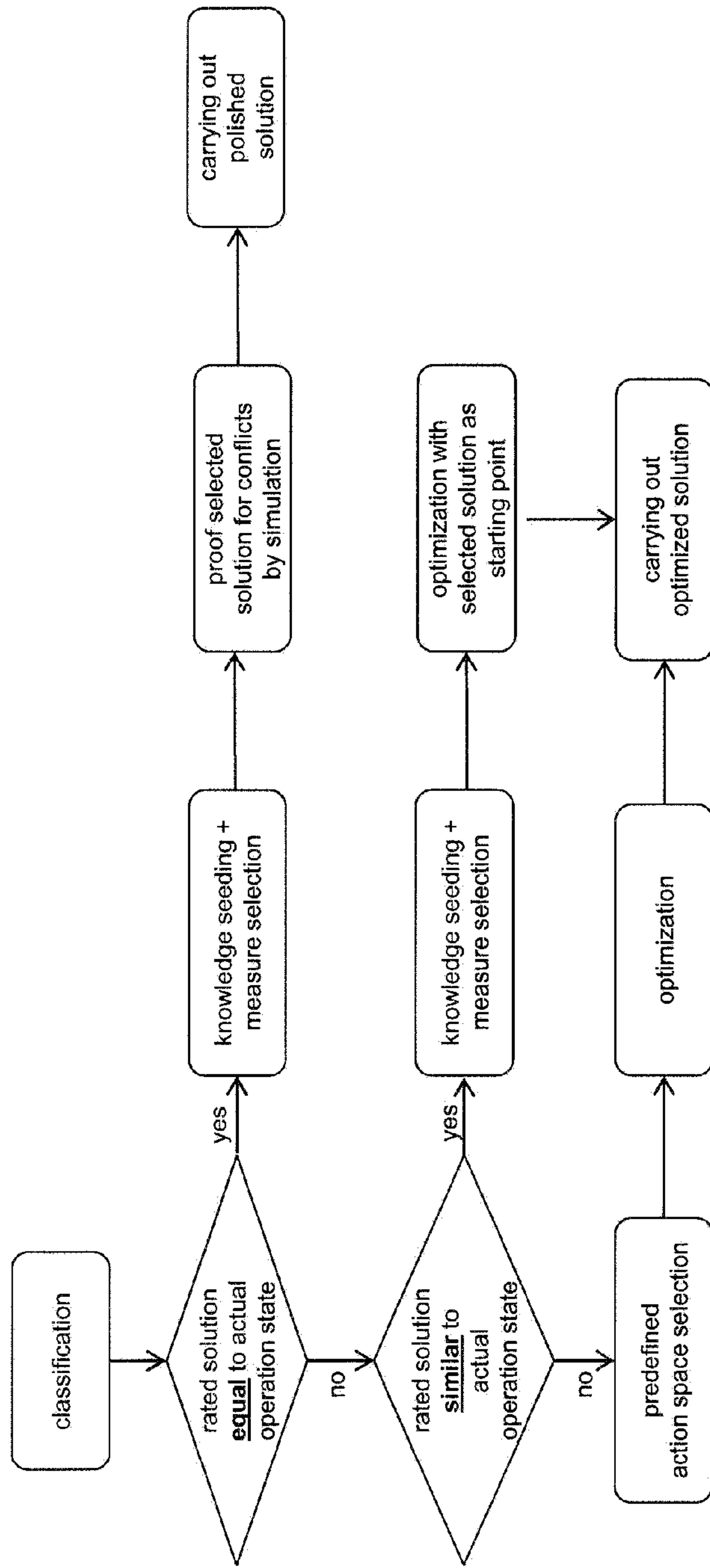


Fig. 3