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(71) Applicant: **TECHNOLOGICAL RESOURCES PTY. LIMITED** [AU/AU]; Level 7, 360 Collins Street, Melbourne, Victoria 3000 (AU).

(72) Inventors: **SHOOK, Andrew Arthur**; 15 Sanctuary Drive, Idalia, Queensland 4811 (AU). **ZEELLENBERG, Jonathon**; 21 Juniper Way, Duncraig, Western Australia

6023 (AU). **ONG, Chong Yew**; 49 A Shearn Crescent, Doubleview, Western Australia 6018 (AU). **STRUWE, Christopher Mark**; 4 Boon Street, Willagee, Western Australia 6156 (AU).

(74) Agent: **GRIFFITH HACK**; Level 22, Allendale Square, 77 St Georges Terrace, Perth, Western Australia 6000 (AU).

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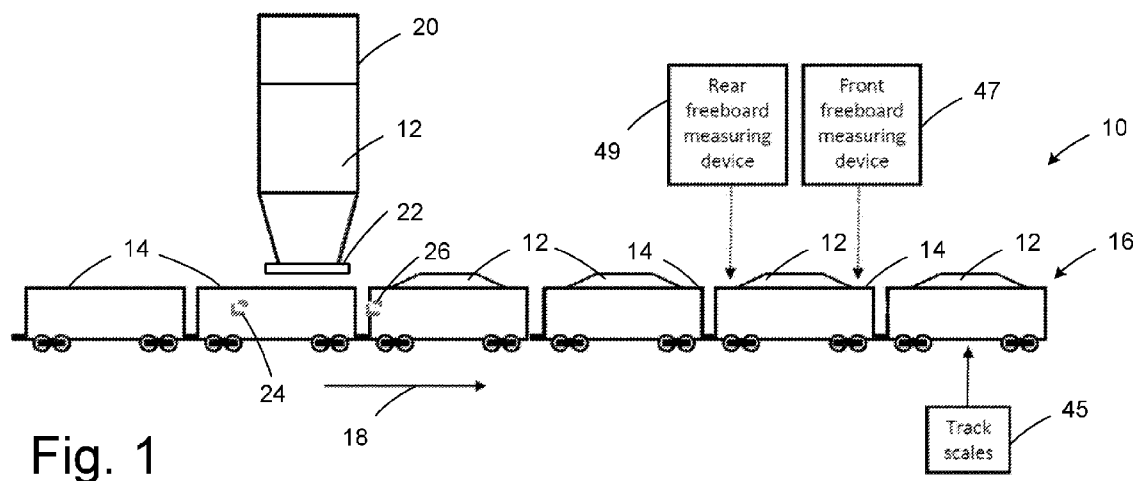


Fig. 1

(57) Abstract: A train loading system is disclosed for loading material onto cars of a train. The system comprises a surge bin arranged to receive material and supply material to cars of a train that travels relative to the surge bin, flow of material from the surge bin being controllable to prevent or permit flow of material from the surge bin and thereby control the volume of material loaded into a car of the train. The system also comprises at least one freeboard measuring device arranged to produce at least one measured freeboard value indicative of a front and/or rear freeboard of a car. The system is arranged to determine a car mass error value representing an error between a car mass value indicative of a mass of material in a car and a defined car mass set point, and to use the car mass error value to produce at least one freeboard set point indicative of desired front and rear freeboard values. The system is also arranged to determine at least one freeboard error value indicative of an error between a measured freeboard value and a freeboard set point and to control timing of flow of material from the surge bin based on the freeboard error value so as to control the mass and volume of material loaded into the car.

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A TRAIN LOADING SYSTEM**Field of the Invention**

5 The present invention relates to a train loading system for loading mined material onto a train at a mine operation.

Background of the Invention

10 It is known to provide a mine operation such as a mine site with a train loading facility arranged to facilitate loading of material onto dedicated material transport trains by train loadout operators.

Typically, ore is carried by a conveyor from a reclaimer to a surge bin, and ore flows
15 out of the surge bin and into cars of the train as the train continuously moves under the bin. Ore flow from the surge bin is determined by an operator by controlling the opening and closing times of a clam, with the aim being to load material into a car such that the volume and mass of material in the car are close to but do not exceed defined limits.

20

Summary of the Invention

It will be understood that in the present specification a mine operation means any operation or facility associated with extracting, handling, processing and/or transporting
25 bulk commodities in a resource extraction environment or part of such a process, for example mine sites, rail facilities, port facilities, and associated infrastructure.

In accordance with a first aspect of the present invention, there is provided a train loading system for loading material onto cars of a train, the system comprising:
30 a surge bin arranged to receive material and supply material to cars of a train that travels relative to the surge bin, wherein flow of material from the surge bin is controllable to prevent or permit flow of material from the surge bin and thereby control the volume of material loaded into a car of the train; and
at least one freeboard measuring device arranged to produce at least one
35 measured freeboard value indicative of a front and/or rear freeboard of a car;

the system arranged to determine a car mass error value representing an error between a car mass value indicative of a mass of material in a car and a defined car mass set point, and to use the car mass error value to produce at least one freeboard set point indicative of desired front and rear freeboard values; and

5 the system arranged to determine at least one freeboard error value indicative of an error between a measured freeboard value and a freeboard set point and to control timing of flow of material from the surge bin based on the freeboard error value so as to control the mass and volume of material loaded into the car.

10 In an embodiment, the car mass value is indicative of a mass of a car after the car has been loaded with material.

In an embodiment, the system includes a weighing device arranged to produce the car mass value after the car has been loaded with material. The weighing device may be
15 disposed at a location at least one car away from the surge bin, for example 4 cars away from the surge bin.

In an embodiment, the system includes a mass estimator, wherein the car mass value is indicative of an estimated car mass before or as the car is loaded with material from
20 the surge bin.

In an embodiment, the system includes at least one car detection sensor arranged to detect presence of a car and determine a train location reference usable to determine a position of the car relative to the surge bin as the car moves relative to the surge bin,
25 the system controlling the timing of flow of material from the surge bin according to the determined position of the car relative to the surge bin.

In an embodiment, the system includes a first car detection sensor arranged to detect presence of a car and determine a first train location reference before the surge bin,
30 the first train location reference usable to determine a front slider position indicative of a position of the car relative to the first train location reference, the system controlling the timing of commencement of ore flow according to the determined front slider position.

In an embodiment, the system includes a second car detection sensor arranged to detect presence of a car and determine a second train location reference after the surge bin, the second train location reference usable to determine a rear slider position indicative of a position of the car relative to the second train location reference, the
 5 system controlling the timing of cessation of ore flow according to the determined rear slider position.

In an embodiment, the first and/or second car detection sensor comprises a photoelectric cell.
 10

In an embodiment, the at least one freeboard measuring device comprises a front freeboard measuring device arranged to produce a front freeboard value indicative of a front freeboard of a car.

15 In an embodiment, the at least one freeboard measuring device comprises a rear freeboard measuring device arranged to produce a rear freeboard value indicative of a rear freeboard of a car.

In an embodiment, the at least one freeboard measuring device is disposed at a
 20 location at least one car away from the surge bin, for example 3 cars away from the surge bin.

The at least one freeboard measuring device may comprise at least one laser measuring device.
 25

In an embodiment, the at least one freeboard measuring device is arranged to produce a raw freeboard value and the system comprises at least one filter arranged to filter the raw freeboard value to produce a filtered freeboard value. The at least one filter may comprise a low pass filter. The at least one filter may be a discrete filter and may be
 30 arranged to implement the following filter algorithm:

$$F_i = \left(\frac{f}{f+1} \right) F_{i-1} + \frac{L_i}{f+1}$$

where F_i is the new filtered freeboard measurement, F_{i-1} is the previous filtered freeboard measurement, L_i is the raw measurement signal received from the laser and f is a filter constant.

- 5 In an embodiment, the system comprises an overload controller arranged to cause cessation of flow of material from the surge bin when the car mass value exceeds a defined value.

10 In an embodiment, if the overload controller has caused flow of material from the surge bin to cease, the system is arranged to use a new filtered rear freeboard measurement if the new filtered freeboard measurement is below the freeboard set point, and to use a previous filtered rear freeboard measurement if the new freeboard measurement is above the freeboard set point.

- 15 In an embodiment, the at least one freeboard set point includes a front freeboard set point associated with a measured front freeboard value and a rear freeboard set point associated with a measured rear freeboard value, the front freeboard set point being substantially the same as the rear freeboard set point.

- 20 In an embodiment, the system comprises a mass controller arranged to use the car mass error value to produce the at least one freeboard set point. The mass controller may be a discrete controller, and may comprise a proportional-integral (PI) controller that may be in velocity form. The mass controller may be arranged to implement the following algorithm:

25

$$m_i = m_{i-1} + K_c(e_i - e_{i-1}) + K_c K_i e_i$$

- 30 where m_i is the new controller output corresponding to a new freeboard set point, m_{i-1} is the previous controller output, K_c is an overall controller gain constant, K_i is an integral gain constant, e_i is a constant error value between the current mass set point value and the current car mass, and e_{i-1} is a previous error value between the previous mass set point value and the previous car mass.

- 35 In an embodiment, the system is arranged to define maximum and minimum values for the freeboard set point.

In an embodiment, the system comprises at least one freeboard controller arranged to control timing of flow of material from the surge bin by controlling the front and/or rear slider position based on the at least one freeboard error value.

5

In an embodiment, the system comprises a front freeboard controller and a rear freeboard controller, the front freeboard controller arranged to use a front freeboard error value indicative of an error between a measured front freeboard value and the freeboard set point to control timing of commencement of flow of material from the surge bin based on the front freeboard error value, and the rear freeboard controller arranged to use a rear freeboard error value indicative of an error between a measured rear freeboard value and the freeboard set point and to control timing of cessation of flow of material from the surge bin based on the rear freeboard error value

15 In an embodiment, the or each freeboard controller is a discrete controller, and may comprise a proportional-integral-derivative (PID) controller that may be in velocity form.

In an embodiment, the or each freeboard controller is a PID-gamma controller.

20 In an embodiment, the or each freeboard controller is arranged to implement the following algorithm:

$$m_i = (1 + a)m_{i-1} - am_{i-2} + e_i(K_p + K_i + b) - e_{i-1}(K_p[1 + a] + aK_i + 2b) + e_{i-2}(K_p a + b) \quad (3)$$

25 where:

m_i is the new controller output, that is, the new slider position in mm;
 m_{i-1} is the current slider position;
 m_{i-2} is the previous slider position;
 30 e_i is the new freeboard error (mm);
 e_{i-1} is the current freeboard error (mm);
 e_{i-2} is the previous freeboard error (mm);
 K_p is a proportional gain parameter;
 K_i is an integral gain parameter;

- b* is a K_d/γ control parameter;
a is an $\exp(-1/\gamma)$ control parameter.

In an embodiment, at commencement of loading of a train and prior to obtaining at
5 least one measured freeboard value indicative of a front and/or rear freeboard of a car,
the system is arranged to set an initialisation freeboard set point value, the initialisation
freeboard set point value being used until the at least one measured freeboard value is
obtained.

10 In an embodiment, the system is arranged such that when front and rear measured
freeboard values are obtained after initialisation, a freeboard set point is determined
based on the front and rear freeboard values, for example by averaging the front and
rear freeboard values.

15 In an embodiment, the system is arranged to adjust the rear slider in response to an
adjustment to the front slider so as to compensate for a change to the rear freeboard
caused by a change to the front slider.

In an embodiment, the system is arranged to facilitate manual adjustment of the timing
20 of flow of material from the surge bin by an operator.

In accordance with a second aspect of the present invention, there is provided a
method of loading material onto cars of a train at a mine operation, the method
comprising:

- 25 receiving material to be loaded onto cars in a surge bin;
supplying material to cars of a train as the train travels relative to the surge bin,
wherein flow of material from the surge bin is controllable to prevent or permit flow of
material from the surge bin and thereby control the volume of material loaded into a car
of the train;
30 producing at least one measured freeboard value indicative of a front and/or
rear freeboard of a car;
determining a car mass error value representing an error between a car mass
value indicative of a mass of material in a car and a defined car mass set point;
using the car mass error value to produce at least one freeboard set point
35 indicative of desired front and rear freeboard values;

determining at least one freeboard error value indicative of an error between a measured freeboard value and a freeboard set point; and

controlling timing of flow of material from the surge bin based on the freeboard error value so as to control the mass and volume of material loaded into the car.

5

Brief Description of the Drawings

The present invention will now be described, by way of example only, with reference to the accompanying drawings, in which:

10

Figure 1 is a diagrammatic perspective representation of a train loading system according to an embodiment of the present invention;

Figure 2 shows timing diagrams representing open and close distances associated with opening and closing of a clam of a surge bin;

15

Figure 3 is a diagrammatic representation of a loaded car of a train illustrating front and rear freeboards;

Figure 4 is a block diagram of a control system of the train loading system shown in Figure 1; and

Figure 5 is a schematic diagram illustrating functional components of the control system shown in Figure 4.

20

Description of an Embodiment of the Invention

An embodiment of a train loading system will now be described with reference to mine operations in the form of mine sites, although it will be understood that other mine operations wherein train loading operations occur are envisaged.

25

An example train loading system 10 is shown diagrammatically in Figure 1.

The train loading system 10 is arranged to load material 12, in this example ore, onto cars 14 of a train 16.

30

During train loading, ore flows out of a surge bin 20 and into cars 14 of the train 20 as the train continuously moves under the surge bin 20 in the direction of arrow 18. The ore flow from the surge bin 20 is controlled by opening and closing a clam 22.

35

In order to fill a car 14 to a volume of material that corresponds closely to a desired car mass level and does not cause material to overflow from the car 14, the clam must be controlled to open and close at the correct times relative to movement of the train 16. However, given that variations may exist between cars, for example because the
5 density of material loaded into each car varies, the optimum clam open and close times may vary for each car 14.

In order to control the timing of clam opening and closing, the system 10 includes a first car detection sensor 24, arranged to provide a first train location reference usable
10 to define the timing of clam opening; and a second car detection sensor 26, arranged to provide a second train location reference usable to define the timing of clam closing.

In this example, the first train location reference is indicative of the location of a front edge of a car 14 prior to movement of the car 14 to a location under the surge bin 20,
15 and the second train location reference is indicative of the location of a rear edge of a car 14 after the car 14 has moved from a location under the surge bin 20, although it will be understood that other arrangements are possible. In this example, each of the first and second car detection sensors 24, 26 includes a photoelectric cell arranged to detect presence of an object in a field of view of the cell, although it will be understood
20 that any suitable sensor capable of detecting presence of a car is envisaged.

Using the determined first and second train location references, the system 10 defines a timing relationship 28 for opening the clam 22 and a timing relationship 30 for closing the clam 22, as shown in Figure 2.

25 As shown in Figure 2, the open timing relationship 28 defines an open distance offset 32 corresponding to the distance of train movement between detection of a car 14 by the first car detection sensor 24 and opening of the clam 22, the open distance offset 32 including a fixed front base component 34 and a front slider component 36 that is
30 variable. It will be understood that the distance defined by the front slider component 36 therefore determines the location of a car 14 relative to the clam 22 when the clam opens, and in this way the front slider component 36 is a variable component that can be used to control the amount of material loaded into the car 14.

Similarly, the close timing relationship 30 defines a close distance offset 38 corresponding to the distance of train movement between detection of a car 14 by the second car detection sensor 26 and closing of the clam 22, the close distance offset 38 including a fixed rear base component 40 and a rear slider component 42 that is
5 variable. It will be understood that the distance defined by the rear slider component 42 therefore determines the location of a car 14 relative to the clam 22 when the clam closes, and in this way the rear slider component 42 is a variable component that can be used to control the amount of material loaded into the car 14.

10 Setting the open and close distances by setting the front and rear slider components 36, 42 in order to modify the amount of material loaded into a car 14 will be referred to in this specification as controlling the "sliders".

During use, the system 10 is capable of adjusting the sliders 36, 42 automatically as
15 necessary in order to account for process variation (such as ore density or variations in flow properties) and thereby control the mass and volume of ore in each car 14.

Figure 3 shows an example fully loaded car 14 of a train 16. As shown, when material 12 is loaded into the car 14, the material forms a mound that may extend above upper
20 edges 43 of the car at a location generally central of the car 14, and may extend below the edges 43 of the car 14 at front and rear ends of the car 14. The distance measured in a generally horizontal direction between a front upper edge of the car 14 and the material 12 is termed the "front freeboard" 44. Similarly, the distance measured in a generally horizontal direction between a rear upper edge of the car 14
25 and the material 12 is termed the "rear freeboard" 46.

It will be appreciated that the front and rear freeboards 44, 46 are indicative of the amount of material in the car 14 in the sense that an increase in the front and/or rear freeboard 44, 46 corresponds to a reduction in the volume of material in the car 14,
30 and a decrease in the front and/or rear freeboard 44, 46 corresponds to an increase in the volume of material in the car 14.

It will also be appreciated that the front and rear freeboards 44, 46 are dependent on the front and rear sliders 36, 42, and therefore by controlling the front and rear sliders,

the front and rear freeboards 44, 46 can be controlled and thereby the mass and volume of material in the car 14 controlled.

As shown in Figure 1, the system also 10 includes a weighing device 45 arranged to
5 determine a net weight value of each car 14 as the car moves forwards, a front freeboard measuring device 47 arranged provide a measured value for the front freeboard 44 of a car 14, and a rear freeboard measuring device 49 arranged provide a measured value for the rear freeboard 46 of the car 14.

10 In this example, the weighing device 45 comprises track scales, although any suitable device for weighing a car 14 is envisaged.

In this example, each of the front and rear freeboard measuring devices 47, 49 includes a laser based measuring device, although it will be understood that any
15 suitable measuring device capable of providing a value indicative of the front and rear freeboards 44, 46 is envisaged.

It will be appreciated that in this example the measured values for the front and rear freeboards 44, 46 are delayed by three cars 14, and the net weight value produced by
20 the weighing device 45 is delayed by four cars.

The system 10 is arranged to automatically adjust the sliders 36, 42 with a view to controlling the mass and volume in a car 14 so that the mass in the car is maintained at a desired mass set point, whilst ensuring that the ore does not overflow from the car
25 14.

For this purpose, the system 10 implements a cascade control arrangement wherein a desired set point for the front and rear freeboards 44, 46 is determined based on a determined error between a desired mass set point and a measured car mass value
30 indicative of an actual car mass (for example provided by the weighing device 45). The desired mass set point is indicative of a desired net mass of a car 14 and the desired set point for the front and rear freeboards 44, 46 is a set point for the front and rear freeboards that is considered to correspond to the desired net mass for the car 14. Based on the determined freeboard set point, values for the front and rear sliders 36,
35 42 are then set.

In this example, the front and rear freeboard set points are the same; that is, the same freeboard set point is used for both the front and rear freeboards 44, 46, which ensures that the mass of material in a car 14 is correctly balanced between the front and rear of the car 14.

A block diagram representing a control system 50 of the train loading system 10 is shown in Figure 4, the control system 50 implementing the cascade control arrangement.

10

The control system 50 includes a mass controller 56 that receives a measured mass value 52 (for example, from the weighing device 45) and a mass set point value 54, and based on the measured mass value 52 and the mass set point value 54 calculates a freeboard set point value 58. The freeboard set point value 58 is for both the front and rear freeboards 44, 46 and as such is provided to a front freeboard controller 60 and a rear freeboard controller 62 which also respectively receive a front freeboard measurement and a rear freeboard measurement from respective front and rear freeboard measuring devices 47, 49. Using a front freeboard error value representing a difference between the freeboard set point 58 and the front freeboard measurement, the front freeboard controller 60 calculates a front adjustment value for an open slider adjuster 64. Similarly, using a rear freeboard error value representing a difference between the freeboard set point 58 and the rear freeboard measurement, the rear freeboard controller 60 calculates a rear adjustment value for a close slider adjuster 66. The open slider adjuster 64 controls the front slider 36 in order to adjust the location of the car 14 relative to the clam 22 when the clam opens. Similarly, the close slider adjuster 66 controls the rear slider 42 in order to adjust the location of the car 14 relative to the clam 22 when the clam closes.

It will be understood that since the system 10 operates on the basis of the mass of each car 14, the mass controller 56, and the front and rear freeboard controllers 60, 62 are of discrete controller type that operate on the basis of individual cars, not time.

Functional components 70 of the train control system 10 are shown in more detail in Figure 5.

35

The functional components 70 include mass control components 72 arranged to produce the freeboard set point value 58 using measured and desired car mass values, and slider control components 74 arranged to use the freeboard set point value 58 to determine the front and rear freeboard adjustment values for the open and close slider adjusters 64, 66.

The mass control components 72 show a mass estimator 76 and the car weighing device 45, one of which provides a car mass value indicative of the mass of a car 14 to an overload controller 78 arranged to generate a close clam instruction 80 when the car mass value exceeds a defined value. The car mass value is also provided to a mass error determiner 86 that calculates a mass error between the mass set point 54 and the car mass value, in this example, the mass set point 54 being defined based on current mass loading statistics 82 and a desired overload rate 84. The mass control components 72 also include the mass controller 56 and auto/manual mass control switch 100.

In this example, the mass controller 56 is a proportional-integral (PI) feedback controller implemented as a discrete controller. As such, the controller does not produce an output until a new railcar mass measurement arrives, either from the car weighing device 45 or the mass estimator 76. When this occurs, a new freeboard set point 58 for the front and rear freeboard controllers 60, 62 is calculated. The mass controller 56 is implemented in velocity form, thus allowing for bumpless transfer with operator actions.

As shown in Figure 5, the mass controller 56 may use either a trackscale measurement from the car weighing device 45 or a car mass estimate from the mass estimator 76 as input. The trackscale measurement is more accurate, but includes a delay which the mass estimator 76 does not. Both reduced accuracy and feedback delay will limit the tunability and performance of the mass controller 56, so the best choice will depend on the relative error of the mass estimator 76 and the distance between the surge bin 20 and the car weighing device 45 for a given site.

Testing has shown that for some cars 14, a total freeboard change of 100mm causes a change in mass of about 2 tonnes, and therefore changing each of the front and back freeboards by about 25 mm will cause about 1 tonne mass change. For other cars 14,

changing each of the front and back freeboards by 25 mm will cause about 2.2 tonnes change in mass.

5 The auto/manual mass control switch 100 is arranged to enable an operator to place the mass controller 56 in manual mode or automatic mode. When the mass controller 56 is in manual mode, the freeboard set point 58 must be initialized to an appropriate value before automatic mode can commence.

10 At commencement of loading of a train 16, no freeboard measurements have yet been provided by the front and rear freeboard measuring devices 47, 49, and consequently the mass controller 56 cannot be placed in automatic mode and instead commences in manual mode. With the mass controller 56 in manual mode, the mass controller output - the freeboard set point 58 - is manually set to an initialisation freeboard set point value. The initialisation freeboard set point value is used until freeboard
15 measurements are provided by the front and rear freeboard measuring devices 47, 49 (after a delay corresponding to 3 cars). When this occurs, the auto/manual mass control switch 100 is set to automatic and the output of the mass controller 56 set to a value corresponding to the current, filtered, freeboard measurements obtained using the front and rear freeboard measuring devices 47, 49.

20

In an example during use with the mass controller 56 in automatic mode, the following parameters exist:

- 25 i) the current car mass set point 54 is 120 tonnes;
- ii) cars are used wherein a change to each of the front and back freeboards 42, 46 by about 25 mm will cause about 1 tonne mass change in the car;
- iii) based on the current car mass set point 54 and the current car mass, the current mass controller output defines a freeboard set point of 50 mm (that is, each of the front and rear freeboards have a freeboard set
30 point of 50 mm);
- iv) the mass of a new car is measured and weighs 117 tonnes net, and therefore the mass error for the new car is therefore $117 - 120 = -3$ tonnes; and

- v) the previous car weighed 118 tonnes so the previous car mass error was -2 tonnes.

In this example, the velocity form of the PI discrete control algorithm implemented by the mass controller 56 to produce a controller output m_i corresponding to the freeboard set point 58 is given by:

$$m_i = m_{i-1} + K_c(e_i - e_{i-1}) + K_c K_i e_i \quad (1)$$

10

where m_i is the new controller output, m_{i-1} is the previous controller output, K_c is an overall controller gain constant, K_i is an integral gain constant, e_i is a constant error value between the current mass set point value 54 and the current car mass, and e_{i-1} is a previous error value between the previous mass set point value 54 and the previous car mass.

15

In simulations, values of 1.8 for K_c and 0.333 for K_i have been found to give reasonable results.

20

Therefore, based on the above parameters, the new controller output m_i is $50 + 1.8*(-3+2) + 1.8*0.333*(-3) = 46.4$ mm.

If another car then arrives with mass of 122 tonnes, the next controller output m_i would be $46.4 + 1.8*(2-(-3)) + 1.8*0.333*2 = 56.6$ mm.

25

It will be appreciated that in this example the calculated controller output values that define the freeboard set point value 58 are constrained to appropriate maximum and minimum freeboard set point values 58 so as to avoid the possibility of the mass controller 56 producing an inappropriate outlier freeboard set point value 58.

30

The raw freeboard measurements produced by the front and rear freeboard measuring devices 47, 49 are noisy. As a consequence, the raw measurement signals produced by the freeboard measuring devices 47, 49 are filtered prior to providing the freeboard measurements to the freeboard controllers 60, 62. Since the raw freeboard

measurement signals arrive intermittently - when a car 14 arrives at the front and rear freeboard measuring devices 47, 49 - a discrete filter algorithm is used.

In the present example, the following discrete filter algorithm is used:

5

$$F_i = \left(\frac{f}{f+1} \right) F_{i-1} + \frac{L_i}{f+1} \quad (2)$$

where F_i is the new freeboard measurement, F_{i-1} is the previous freeboard measurement, L_i is the raw measurement signal received from the laser and f is a filter constant.

If the overload controller 78 has closed the clam 22 early on a car 14, the rear freeboard 46 will potentially be relatively large compared to the freeboard set point. In order to compensate for a falsely large rear freeboard 46 and thereby avoid the rear freeboard controller 62 winding up in response to intervention by the overload controller 78, the system 10 is arranged to use the new freeboard measurement F_i if the new freeboard measurement F_i is below the freeboard set point, and to use the previous freeboard measurement F_{i-1} if the new freeboard measurement F_i is above the freeboard set point.

In an example during use, a previous front freeboard measurement F_i was 10mm, a previous rear freeboard measurement F_i was 25mm, a new raw laser measurement L_i of 60mm is received for the front freeboard of the next car, and a new raw laser measurement L_i of 80mm is received for the rear freeboard of the next car. The set point for both the front and rear freeboard was 30mm, and f is 0.5.

Using equation (2) above, the new front freeboard measurement F_i corresponding to the new front freeboard raw laser measurement L_i is given by $(0.5/1.5)*10 + 60/1.5 = 43.33$ mm.

However, since the overload controller 78 closed the clam 22 prematurely on this car, the rear freeboard measurement is falsely large, and since the new freeboard estimate F_i is above the set point, the previous freeboard measurement F_{i-1} of 25mm is used for the new rear freeboard measurement F_i .

It will be appreciated that selection of the filter constant f is important and will affect the tuning of the front and rear freeboard controllers 60, 62.

5 The slider control components 74 include a front low pass filter 92 for filtering the raw front freeboard measurement 93 received from the front freeboard measuring device 47, in this example by applying the discrete filter algorithm shown in equation (2), and a rear low pass filter 94 for filtering the raw rear freeboard measurement 95 received from the rear freeboard measuring device 49, in this example by applying the discrete
10 filter algorithm shown in equation (2).

The filtered front freeboard measurement and the freeboard set point 58 are provided to a front freeboard error determiner 88 that calculates a front freeboard error indicative of the difference between the filtered front freeboard measurement and the freeboard
15 set point 58. Similarly, the filtered rear freeboard measurement and the freeboard set point 58 are provided to a rear freeboard error determiner 90 that calculates a rear freeboard error indicative of the difference between the filtered rear freeboard measurement and the freeboard set point 58.

20 The front freeboard error is provided to the front freeboard controller 60 that uses the front freeboard error to produce the front slider adjustment value for the open slider adjuster 64. Similarly, the rear freeboard error is provided to the rear freeboard controller 62 that uses the rear freeboard error to produce the rear slider adjustment value for the close slider adjuster 66.

25 The slider control components 74 also include a front manual adjustment control 102 and rear manual adjustment control 104 usable to facilitate manual adjustment of the front and rear sliders respectively by an operator and thereby override the automatic slider control provided by the system 10.

30 In this example, the outputs of the front and rear freeboard controllers 60, 62 are constrained to appropriate maximum and minimum values to prevent windup.

In this example, the front and rear freeboard controllers 60, 62 are proportional-
35 integral-derivative (PID) controllers that are implemented as discrete controllers. As

such, the front and rear sliders 36, 42 are only updated by the front and rear freeboard controllers 60, 62 when additional measurements arrive. In addition, the front and rear sliders 36, 42 are only allowed to be updated if the clam is closed.

- 5 In this example, the front and rear freeboard controllers 60, 62 are implemented in velocity form, thus simultaneously allowing discrete operation and making bumpless transfer from manual adjustments simpler.

10 It will be understood that changing the timing of opening of the clam 22 changes the rear freeboard 46 in addition to the front freeboard 44, because the amount of material that is initially loaded into the car, including a rear portion of the car 14, will change by changing the front slider 36. As a result, in order to compensate for changes to the rear slider 42 because of changes to the front slider 36, an adjustment is made to the rear slider 42. In the present example, a rear freeboard compensation value 96
15 corresponding to at least a portion of the calculated changes to the front slider 36 is subtracted from the calculated changes to the rear slider 42, as shown in Figure 5.

However, if the mass overload controller 78 has closed the clam 22 early to the extent that the current rear freeboard 46 is below the freeboard set point 58, the rear
20 freeboard compensation value 96 is not passed on to the rear freeboard controller 62. Without this, the rear freeboard controller could wind up.

The front and rear freeboard controllers 60, 62 operate on a discrete basis and need to cope with the time delay imposed by the freeboard measuring devices 47, 49, as well
25 as the lag imposed by the low pass filters 92, 94. For this reason, in this example PID-gamma controllers are used for the front and rear freeboard controllers 60, 62.

In this example, the discrete velocity form of a PID-gamma controller is as follows:

$$30 \quad m_i = (1+a)m_{i-1} - am_{i-2} + e_i(K_p + K_i + b) - e_{i-1}(K_p[1+a] + aK_i + 2b) + e_{i-2}(K_p a + b) \quad (3)$$

where:

m_i is the new controller output, that is, the new slider position in mm;

- m_{i-1} is the current slider position;
 m_{i-2} is the previous slider position;
 e_i is the new freeboard error (mm), noting that the error sense is reversed for front and rear freeboard.
 5 e_{f-1} is the current freeboard error (mm);
 e_{f-2} is the previous freeboard error (mm);
 K_p is the proportional gain – a controller tuning parameter;
 K_i is the integral gain – a controller tuning parameter;
 b is K_d/γ – a controller tuning parameter
 10 a is $\exp(-1/\gamma)$ – a controller tuning parameter

This control form can be coded into a PLC as an algorithm that only executes when a new freeboard measurement arrives from a freeboard measuring device 47, 49.

- 15 Internal model control (IMC) tuning rules for the PID-gamma controller have provided the following suggestions for initial controller tuning parameters:

- $K_p = 0.05$
 $K_i = 0.066$
 20 $a = 0.434$
 $b = -0.01167$

In an example during use, the following parameters exist:

Parameter	Value
Current open slider position, $m_{o,1}$	95 mm
Previous open slider position, $m_{o,2}$	90 mm
Front freeboard set point	50 mm
New filtered front freeboard measurement	47 mm
Current filtered front freeboard measurement	45 mm
Previous filtered front freeboard measurement	40 mm
Current close slider position, $m_{c,1}$	55 mm
Previous close slider position, $m_{c,2}$	50 mm
Rear freeboard set point	50 mm
New filtered rear freeboard measurement	57 mm
Current filtered rear freeboard measurement	60 mm
Previous filtered rear freeboard measurement	62 mm

25

Table 3

Based on these values, the error values e_i , e_{i-1} , e_{i-2} are calculated, as follows:

Front	Rear
$e_i = 47 - 50 = -3$	$e_i = 57 - 50 = 7$
$e_{i-1} = 45 - 50 = -5$	$e_{i-1} = 60 - 50 = 10$
$e_{i-2} = 40 - 50 = -10$	$e_{i-2} = 62 - 50 = 12$

Table 4

5

Using the values in Table 3 and Table 4, the new front slider m_i is calculated as follows:

$$m_i (\text{front}) = (1+0.434)*95 - 0.434*90 - 3*(0.05+0.066-0.01167) + 5*(0.05*(1+0.434) + 0.434*0.066 - 2(0.01167)) - 10*(0.434*0.05-0.01167) = 97.1 \text{ mm}$$

10

Similarly, the new rear slider m_i is calculated using the values in Table 3 and Table 4 as follows:

$$m_i (\text{rear}) = (1+0.434)*55 - 0.434*50 + 7*(0.05+0.066-0.01167) - 10*(0.05*(1+0.434) + 0.434*0.066 - 2(0.01167)) + 12*(0.434*0.05-0.01167) = 57.3 \text{ mm}$$

15

Accordingly, in this example it can be seen that with successive cars, the front and rear freeboard controllers 60, 62 cause the freeboards 44, 46 to trend towards the freeboard set point and the front slider to gradually increase in order to effect a gradual reduction in the front freeboard.

20

As discussed above, the overload controller 78 is arranged to close the clam 22 early in response to a high likelihood of mass overload of a car 14. Closing the clam early has the effect of increasing the rear freeboard and reducing the mass of ore loaded into the car 14. Frequent intervention by the overload controller 78 has the potential to cause wind up in the rear freeboard controller 62 and the mass controller 56.

25

The impact of the overload controller 78 on the rear freeboard controller 62 can be reduced by estimating what the rear freeboard 46 would have been if the overload controller 78 had not intervened. This can be done by subtracting the "early close distance" (the distance between the rear slider 42 and the actual position of the car

30

when the overload controller 78 caused the clam 22 to close) from the measured rear freeboard measurement 95 for the car. The adjusted value is then used as an input to the rear freeboard filter 94.

- 5 The impact of the overload controller 78 on the mass controller 56 can be reduced by adding a “tonnes removed” mass value corresponding to the early close distance multiplied by a constant of approximately 13 tonnes per metre to the measured mass for the car. The adjusted value of mass is then used as an input to the mass controller 56 so that the current mass value input to the mass error determiner 86 more
10 accurately represents the car mass value that will have occurred if the overload controller 78 had not intervened.

The averaged value of the current filtered front and rear freeboard measurements should be used as the initial output of the mass controller 56 when the mass controller
15 56 is first switched to automatic mode.

In the example above, the current front and rear filtered freeboard measurements m_{i-1} are 47mm and 57mm respectively. If the mass controller 56 is currently in automatic mode, switching the mass controller 56 to manual mode then immediately back to
20 automatic mode would cause the set point for the front and rear freeboard controllers 60, 62 to be set to $(47+57)/2 = 52\text{mm}$. In this circumstance, 52mm would also be the value used by the mass controller 56 for the values in equation (1) for the new and current freeboard set points m_i, m_{i-1} .

25 Because the velocity form of the PID controllers has been used, transfer between automatic and manual modes is straightforward for the freeboard controllers 60, 62. When the freeboard controllers 60, 62 are in manual mode, the control calculation defined in equation (3) is not executed, and the latest (manual) value for m_i is used for the current and previous slider positions m_{i-1}, m_{i-2} . Similarly, the current value for the
30 new freeboard error e_i is used and the current and previous freeboard error values e_{i-1}, e_{i-2} are also set to this value. This ensures that there is no “bump” and the controller restarts normally.

The operator is able to adjust the sliders 36, 42 while the controllers are in automatic
35 mode, and any adjustment made is treated as a brief transition into manual mode and

back to automatic mode such that the mass and freeboard controllers 56, 60, 62 are reset as described above.

Controller tuning, and particularly freeboard controller tuning, is important to the reliability of the system 10. The freeboard controllers 60, 62 should be tuned first before tuning the mass controller 56. The initial tuning process may follow a procedure according to the following:

- 10 • Establish stable loading conditions with the mass and freeboard controllers 56, 60, 62 in manual mode;
- Put the rear freeboard controller 62 in automatic mode, with both the mass controller 56 and the front freeboard controller 60 in manual mode;
- Make a step change to the freeboard set point 58, observe the effect on the rear freeboard controller 62 and tune as normal.
- 15 • Leave the rear freeboard controller 62 in automatic mode and tune the front freeboard controller 60, verifying that the decoupling of the front and rear controllers 60, 62 is effective;
- Load several cars 14 with the front and rear freeboard controllers 60, 62 in automatic mode, but providing manual step set point changes to the freeboard, and verifying that the combined performance is acceptable; and
- 20 • Place the mass controller in automatic mode with appropriate controller gains as set by the observation of the response to the manual set point changes.

25 In order for the system to perform safely and well, it is important that the freeboard measuring devices are operating reliably. A permissive should be installed such that the freeboard controllers 60, 62 cannot be put into automatic mode unless the freeboard measuring devices are running properly.

30 Once the system 10 is operating in automatic mode, if a valid freeboard signal has not been detected for five cars, then the system 10 may be arranged so as to place the controllers 56, 60, 62 in manual mode with the system not allowing the controllers 56, 60, 62 to move to automatic mode until at least one valid freeboard signal has been received.

It is to be understood that, if any prior art publication is referred to herein, such reference does not constitute an admission that the publication forms a part of the common general knowledge in the art, in Australia or any other country.

- 5 In the claims which follow and in the preceding description of the invention, except where the context requires otherwise due to express language or necessary implication, the word "comprise" or variations such as "comprises" or "comprising" is used in an inclusive sense, i.e. to specify the presence of the stated features but not to preclude the presence or addition of further features in various embodiments of the
10 invention.

Modifications and variations as would be apparent to a skilled addressee are deemed to be within the scope of the present invention.

CLAIMS:

1. A train loading system for loading material onto cars of a train, the system comprising:
 - 5 a surge bin arranged to receive material and supply material to cars of a train that travels relative to the surge bin, wherein flow of material from the surge bin is controllable to prevent or permit flow of material from the surge bin and thereby control the volume of material loaded into a car of the train; and
 - at least one freeboard measuring device arranged to produce at least one
 - 10 measured freeboard value indicative of a front and/or rear freeboard of a car;
 - the system arranged to determine a car mass error value representing an error between a car mass value indicative of a mass of material in a car and a defined car mass set point, and to use the car mass error value to produce at least one freeboard set point indicative of desired front and rear freeboard values; and
 - 15 the system arranged to determine at least one freeboard error value indicative of an error between a measured freeboard value and a freeboard set point and to control timing of flow of material from the surge bin based on the freeboard error value so as to control the mass and volume of material loaded into the car.
- 20 2. A train loading system as claimed in claim 1, wherein the car mass value is indicative of a mass of a car after the car has been loaded with material.
3. A train loading system as claimed in claim 2, wherein the system includes a weighing device arranged to produce the car mass value after the car has been loaded
- 25 with material.
4. A train loading system as claimed in claim 1, comprising a mass estimator, wherein the car mass value is indicative of an estimated car mass before or as the car is loaded with material from the surge bin.
- 30 5. A train loading system as claimed in any one of the preceding claims, comprising at least one car detection sensor arranged to detect presence of a car and determine a train location reference usable to determine a position of the car relative to the surge bin as the car moves relative to the surge bin, the system controlling the

timing of flow of material from the surge bin according to the determined position of the car relative to the surge bin.

6. A train loading system as claimed in claim 5, wherein the at least one car
5 detection sensor comprises a first car detection sensor arranged to detect presence of a car and determine a first train location reference before the surge bin, the first train location reference usable to determine a front slider position indicative of a position of the car relative to the first train location reference, the system controlling the timing of commencement of ore flow according to the determined front slider position.

10

7. A train loading system as claimed in claim 6, wherein the at least one car
detection sensor comprises a second car detection sensor arranged to detect
presence of a car and determine a second train location reference after the surge bin,
the second train location reference usable to determine a rear slider position indicative
15 of a position of the car relative to the second train location reference, the system
controlling the timing of cessation of ore flow according to the determined rear slider
position.

8. A train loading system as claimed in claim 7, wherein the first and/or second
20 car detection sensor comprises a photoelectric cell.

9. A train loading system as claimed in any one of the preceding claims, wherein
the at least one freeboard measuring device comprises a front freeboard measuring
device arranged to produce a front freeboard value indicative of a front freeboard of a
25 car.

10. A train loading system as claimed in any one of the preceding claims, wherein
the at least one freeboard measuring device comprises a rear freeboard measuring
device arranged to produce a rear freeboard value indicative of a rear freeboard of a
30 car.

11. A train loading system as claimed in any one of the preceding claims, wherein
the at least one freeboard measuring device is disposed at a location at least one car
away from the surge bin.

35

12. A train loading system as claimed in any one of the preceding claims, wherein the at least one freeboard measuring device comprises at least one laser measuring device.

5 13. A train loading system as claimed in any one of the preceding claims, wherein the at least one freeboard measuring device is arranged to produce a raw freeboard value and the system comprises at least one filter arranged to filter the raw freeboard value to produce a filtered freeboard value.

10 14. A train loading system as claimed in claim 13, wherein the at least one filter comprises a low pass filter.

15. A train loading system as claimed in claim 14, wherein the at least one filter is a discrete filter arranged to implement the following filter algorithm:

$$F_i = \left(\frac{f}{f+1} \right) F_{i-1} + \frac{L_i}{f+1}$$

where F_i is the new filtered freeboard measurement, F_{i-1} is the previous filtered freeboard measurement, L_i is the raw measurement signal received from the laser and f is a filter constant.

16. A train loading system as claimed in any one of the preceding claims, wherein the system comprises an overload controller arranged to cause cessation of flow of material from the surge bin when the car mass value exceeds a defined value.

17. A train loading system as claimed in claim 16, wherein if the overload controller has caused flow of material from the surge bin to cease, the system is arranged to use a new filtered rear freeboard measurement if the new filtered freeboard measurement is below the freeboard set point, and to use a previous filtered rear freeboard measurement if the new freeboard measurement is above the freeboard set point.

18. A train loading system as claimed in any one of the preceding claims, wherein the at least one freeboard set point includes a front freeboard set point associated with a measured front freeboard value and a rear freeboard set point associated with a

measured rear freeboard value, the front freeboard set point being substantially the same as the rear freeboard set point.

19. A train loading system as claimed in any one of the preceding claims, wherein
5 the system comprises a mass controller arranged to use the car mass error value to produce the at least one freeboard set point.

20. A train loading system as claimed in claim 19, wherein the mass controller is a
10 discrete controller.

21. A train loading system as claimed in claim 20, wherein the mass controller
comprises a proportional-integral (PI) controller.

22. A train loading system as claimed in claim 21, wherein the proportional-integral
15 (PI) controller is in in velocity form.

23. A train loading system as claimed in any one of claims 20 to 22, wherein the
mass controller is arranged to implement the following algorithm:

$$20 \quad m_i = m_{i-1} + K_c(e_i - e_{i-1}) + K_i K_c e_i$$

where m_i is the new controller output corresponding to a new freeboard set point, m_{i-1}
is the previous controller output, K_c is an overall controller gain constant, K_i is an
25 integral gain constant, e_i is a constant error value between the current mass set point
value and the current car mass, and e_{i-1} is a previous error value between the previous
mass set point value and the previous car mass.

24. A train loading system as claimed in any one of the preceding claims, wherein
30 the system is arranged to define maximum and minimum values for the freeboard set
point.

25. A train loading system as claimed in any one of the preceding claims, wherein
the system comprises at least one freeboard controller arranged to control timing of
35 flow of material from the surge bin by controlling the front and/or rear slider position
based on the at least one freeboard error value.

26. A train loading system as claimed in claim 25, wherein the system comprises a front freeboard controller and a rear freeboard controller, the front freeboard controller arranged to use a front freeboard error value indicative of an error between a
 5 measured front freeboard value and the freeboard set point to control timing of commencement of flow of material from the surge bin based on the front freeboard error value, and the rear freeboard controller arranged to use a rear freeboard error value indicative of an error between a measured rear freeboard value and the freeboard set point and to control timing of cessation of flow of material from the surge
 10 bin based on the rear freeboard error value

27. A train loading system as claimed in claim 25 or claim 26, wherein the or each freeboard controller is a discrete controller.

15 28. A train loading system as claimed in claim 27, wherein the or each freeboard controller comprises a proportional-integral-derivative (PID) controller.

29. A train loading system as claimed in claim 28, wherein the proportional-integral-derivative (PID) controller is in velocity form.

20 30. A train loading system as claimed in claim 29, wherein the PID controller is a PID-gamma controller.

31. A train loading system as claimed in claim 27, wherein the or each freeboard
 25 controller comprises a proportional-integral-derivative (PID) controller.

32. A train loading system as claimed in any one of claims 25 to 31, wherein the or each freeboard controller is arranged to implement the following algorithm:

30
$$m_i = (1+a)m_{i-1} - am_{i-2} + e_i(K_p + K_i + b) - e_{i-1}(K_p[1+a] + aK_i + 2b) + e_{i-2}(K_p a + b) \quad (3)$$

where:

m_i is the new controller output, that is, the new slider position in mm;

m_{i-1} is the current slider position;
 m_{i-2} is the previous slider position;
 e_i is the new freeboard error (mm);
 e_{i-1} is the current freeboard error (mm);
 5 e_{i-2} is the previous freeboard error (mm);
 K_p is a proportional gain parameter;
 K_i is an integral gain parameter;
 b is a Kd/gamma control parameter;
 a is an $\exp(-1/\text{gamma})$ control parameter.

10

33. A train loading system as claimed in any one of the preceding claims, wherein at commencement of loading of a train and prior to obtaining at least one measured freeboard value indicative of a front and/or rear freeboard of a car, the system is arranged to set an initialisation freeboard set point value, the initialisation freeboard set point value being used until the at least one measured freeboard value is obtained.

15

34. A train loading system as claimed in claim 33, wherein the system is arranged such that when front and rear measured freeboard values are obtained after initialisation, a freeboard set point is determined based on the front and rear freeboard values.

20

35. A train loading system as claimed in any one of the preceding claims, wherein the system is arranged to adjust the rear slider in response to an adjustment to the front slider so as to compensate for a change to the rear freeboard caused by a change to the front slider.

25

36. A train loading system as claimed in any one of the preceding claims, wherein the system is arranged to facilitate manual adjustment of the timing of flow of material from the surge bin by an operator.

30

37. A method of loading material onto cars of a train at a mine operation, the method comprising:
 receiving material to be loaded onto cars in a surge bin;
 supplying material to cars of a train as the train travels relative to the surge bin,
 35 wherein flow of material from the surge bin is controllable to prevent or permit flow of

35

material from the surge bin and thereby control the volume of material loaded into a car of the train;

producing at least one measured freeboard value indicative of a front and/or rear freeboard of a car;

5 determining a car mass error value representing an error between a car mass value indicative of a mass of material in a car and a defined car mass set point;

using the car mass error value to produce at least one freeboard set point indicative of desired front and rear freeboard values;

10 determining at least one freeboard error value indicative of an error between a measured freeboard value and a freeboard set point; and

controlling timing of flow of material from the surge bin based on the freeboard error value so as to control the mass and volume of material loaded into the car.

38. A method as claimed in claim 37, wherein the car mass value is indicative of a mass of a car after the car has been loaded with material.

39. A method as claimed in claim 38, comprising producing the car mass value after the car has been loaded with material using a weighing device.

20 40. A method as claimed in claim 37, wherein the car mass value is indicative of an estimated car mass before or as the car is loaded with material from the surge bin.

41. A method as claimed in any one of claims 37 to 40, comprising detecting presence of a car and determining a train location reference usable to determine a position of the car relative to the surge bin as the car moves relative to the surge bin, and controlling the timing of flow of material from the surge bin according to the determined position of the car relative to the surge bin.

42. A method as claimed in claim 41, comprising using a first car detection sensor to detect presence of a car and determine a first train location reference before the surge bin, the first train location reference usable to determine a front slider position indicative of a position of the car relative to the first train location reference, and controlling the timing of commencement of ore flow according to the determined front slider position.

43. A method as claimed in claim 42, comprising using a second car detection sensor arranged to detect presence of a car and determine a second train location reference after the surge bin, the second train location reference usable to determine a rear slider position indicative of a position of the car relative to the second train location reference, and controlling the timing of cessation of ore flow according to the determined rear slider position.

44. A method as claimed in claim 43, wherein the first and/or second car detection sensor comprises a photoelectric cell.

10

45. A method as claimed in any one of claims 37 to 44, comprising using a front freeboard measuring device to produce a front freeboard value indicative of a front freeboard of a car.

15 46. A method as claimed in any one of claims 37 to 45, comprising using a rear freeboard measuring device to produce a rear freeboard value indicative of a rear freeboard of a car.

20 47. A method as claimed in any one of claims 37 to 46, comprising producing a raw freeboard value and filtering the raw freeboard value to produce a filtered freeboard value.

48. A method as claimed in claim 47, wherein the filtering comprises using a low pass filter.

25

49. A method as claimed in claim 48, wherein the low pass filter is a discrete filter arranged to implement the following filter algorithm:

$$F_i = \left(\frac{f}{f+1} \right) F_{i-1} + \frac{L_i}{f+1}$$

where F_i is the new filtered freeboard measurement, F_{i-1} is the previous filtered freeboard measurement, L_i is the raw measurement signal received from the laser and f is a filter constant.

35

50. A method as claimed in any one of claims 37 to 49, comprising causing cessation of flow of material from the surge bin when the car mass value exceeds a defined value.

5 51. A method as claimed in claim 50, wherein if flow of material from the surge bin is caused to cease, using a new filtered rear freeboard measurement if the new filtered freeboard measurement is below the freeboard set point, and using a previous filtered rear freeboard measurement if the new freeboard measurement is above the freeboard set point.

10

52. A method as claimed in any one of claims 37 to 51, wherein the at least one freeboard set point includes a front freeboard set point associated with a measured front freeboard value and a rear freeboard set point associated with a measured rear freeboard value, the front freeboard set point being substantially the same as the rear
15 freeboard set point.

53. A method as claimed in any one of claims 37 to 52, comprising providing a mass controller arranged to use the car mass error value to produce the at least one freeboard set point.

20

54. A method as claimed in claim 53, wherein the mass controller is a discrete controller.

25 55. A method as claimed in claim 53, wherein the mass controller comprises a proportional-integral (PI) controller.

56. A method as claimed in claim 55, wherein the proportional-integral (PI) controller is in in velocity form.

30 57. A method as claimed in any one of claims 53 to 56, wherein the mass controller is arranged to implement the following algorithm:

$$m_i = m_{i-1} + K_c(e_i - e_{i-1}) + K_c K_i e_i$$

35

where m_i is the new controller output corresponding to a new freeboard set point, m_{i-1} is the previous controller output, K_c is an overall controller gain constant, K_i is an integral gain constant, e_i is a constant error value between the current mass set point value and the current car mass, and e_{i-1} is a previous error value between the previous mass set point value and the previous car mass.

58. A method as claimed in any one of claims 37 to 57, comprising defining maximum and minimum values for the freeboard set point.
59. A method as claimed in any one of claims 37 to 58, comprising providing at least one freeboard controller arranged to control timing of flow of material from the surge bin by controlling the front and/or rear slider position based on the at least one freeboard error value.
60. A method as claimed in claim 59, comprising providing a front freeboard controller and a rear freeboard controller, the front freeboard controller arranged to use a front freeboard error value indicative of an error between a measured front freeboard value and the freeboard set point to control timing of commencement of flow of material from the surge bin based on the front freeboard error value, and the rear freeboard controller arranged to use a rear freeboard error value indicative of an error between a measured rear freeboard value and the freeboard set point and to control timing of cessation of flow of material from the surge bin based on the rear freeboard error value
61. A method as claimed in claim 59 or claim 60, wherein the or each freeboard controller is a discrete controller.
62. A method as claimed in claim 61, wherein the or each freeboard controller comprises a proportional-integral-derivative (PID) controller.
63. A method as claimed in claim 62, wherein the proportional-integral-derivative (PID) controller is in velocity form.
64. A method as claimed in claim 63, wherein the PID controller is a PID-gamma controller.

65. A method as claimed in claim 61, wherein the or each freeboard controller comprises a proportional-integral-derivative (PID) controller.

5 66. A method as claimed in any one of claims 59 to 65, wherein the or each freeboard controller is arranged to implement the following algorithm:

$$m_i = (1 + a)m_{i-1} - am_{i-2} + e_i(K_p + K_i + b) - e_{i-1}(K_p[1 + a] + aK_i + 2b) + e_{i-2}(K_p a + b) \quad (3)$$

10 where:

m_i is the new controller output, that is, the new slider position in mm;
 m_{i-1} is the current slider position;
 m_{i-2} is the previous slider position;
 15 e_i is the new freeboard error (mm);
 e_{i-1} is the current freeboard error (mm);
 e_{i-2} is the previous freeboard error (mm);
 K_p is a proportional gain parameter;
 K_i is an integral gain parameter;
 20 b is a Kd/gamma control parameter;
 a is an $\exp(-1/\text{gamma})$ control parameter.

67. A method as claimed in any one of claims 37 to 66, comprising setting an initialisation freeboard set point value at commencement of loading of a train and prior
 25 to obtaining at least one measured freeboard value indicative of a front and/or rear freeboard of a car, the initialisation freeboard set point value being used until the at least one measured freeboard value is obtained.

68. A method as claimed in claim 67, comprising determining a freeboard set point
 30 based on the front and rear freeboard values when front and rear measured freeboard values are obtained after initialisation.

69. A method as claimed in any one of claims 37 to 68, comprising adjusting the rear slider in response to an adjustment to the front slider so as to compensate for a change to the rear freeboard caused by a change to the front slider.
- 5 70. A method as claimed in any one of claims 37 to 69, comprising facilitating manual adjustment of the timing of flow of material from the surge bin by an operator.

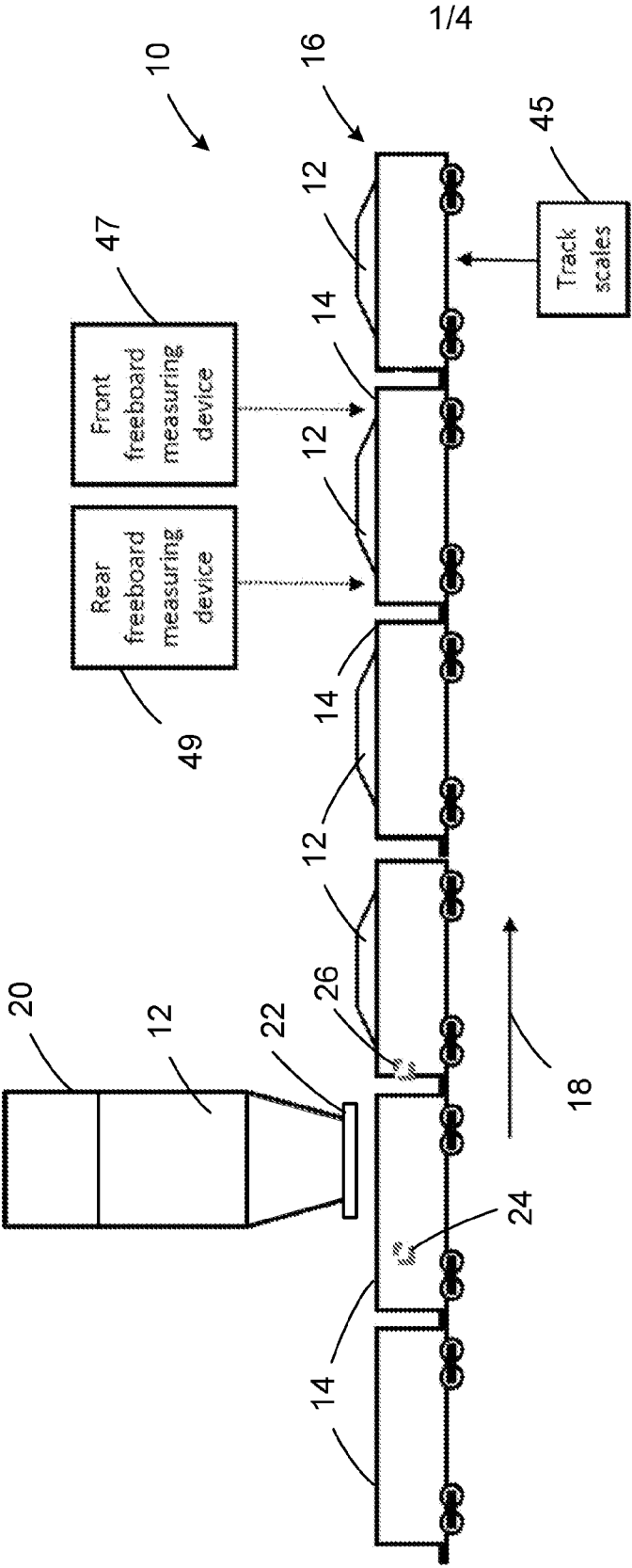


Fig. 1

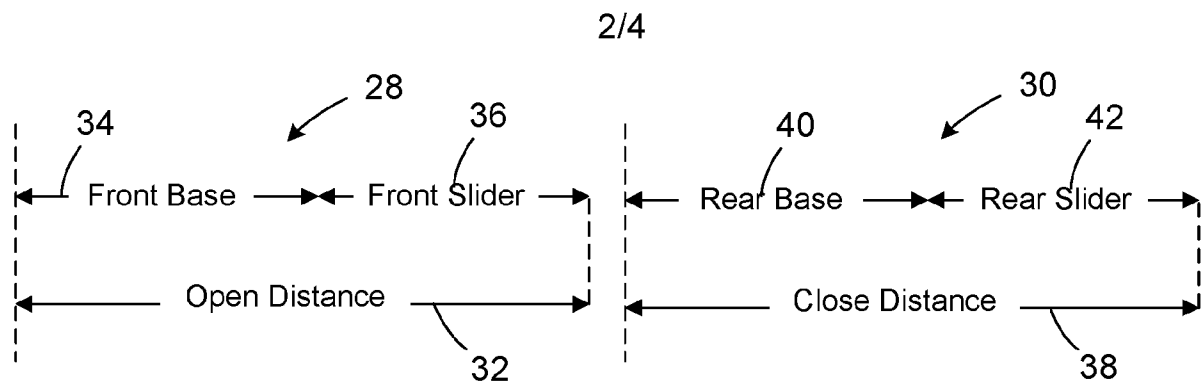


Fig. 2

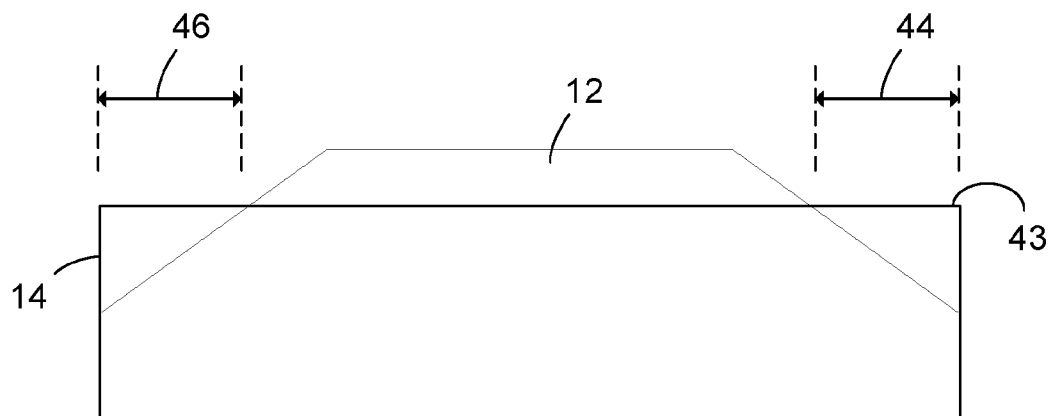
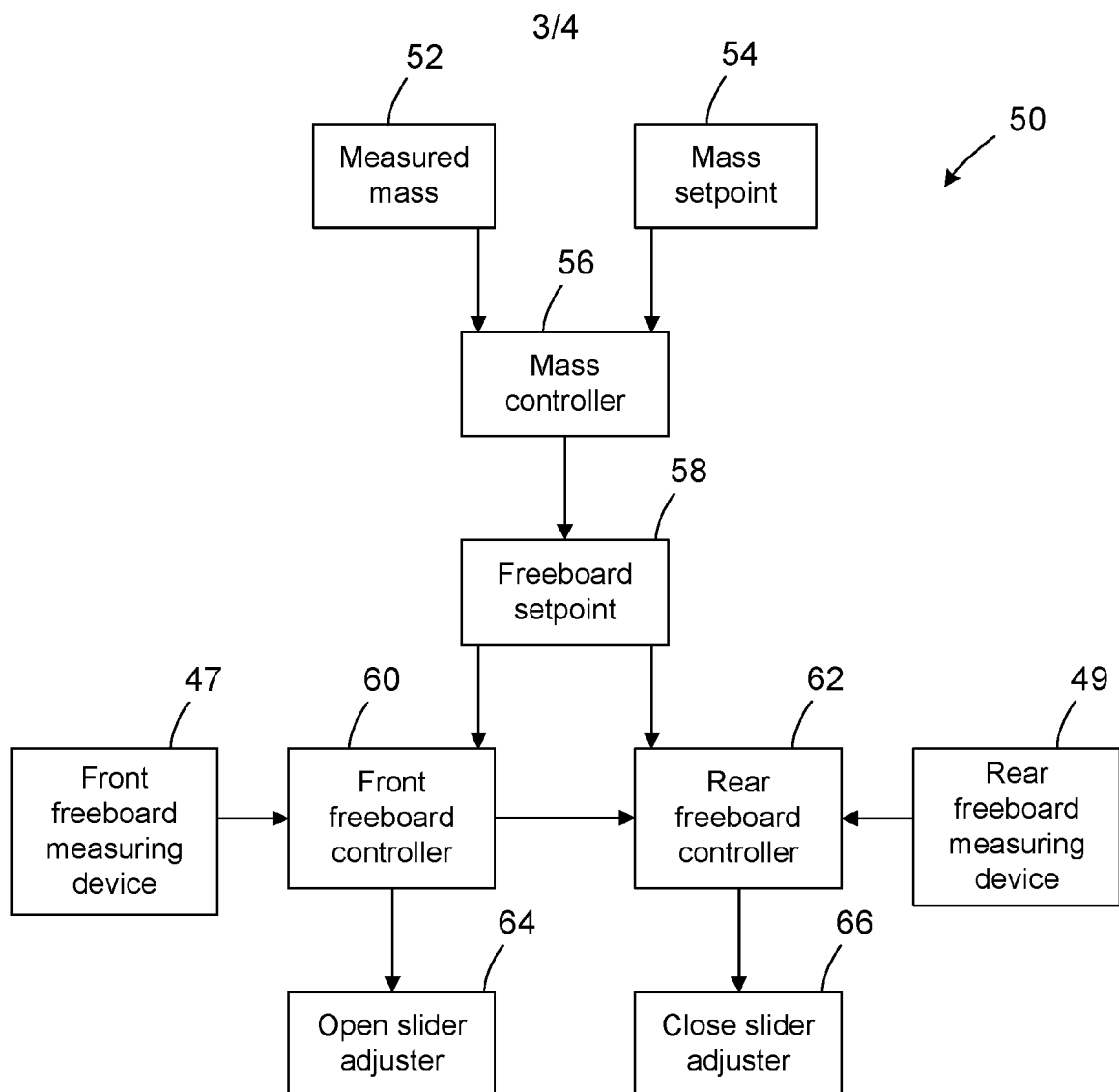
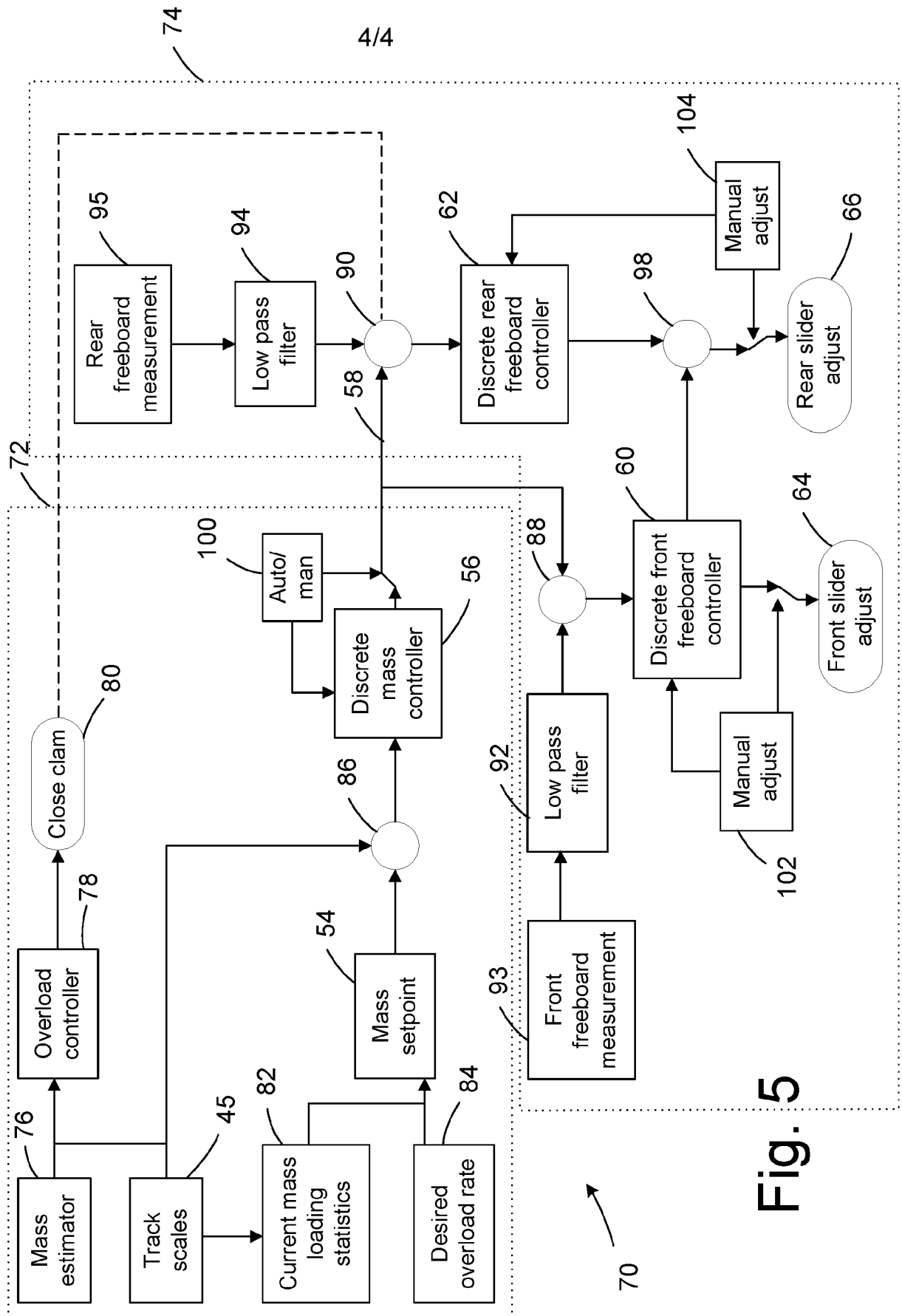


Fig. 3

**Fig. 4**



INTERNATIONAL SEARCH REPORT

International application No.
PCT/AU2018/050469

A. CLASSIFICATION OF SUBJECT MATTER

B65G 67/22 (2006.01) B65G 69/02 (2006.01)

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

PATENW; IPC/CPC: B65G 63/067, 63/008, B65G 67/04, 67/22, 69/02, B65G 2814/0349, 2814/0344, 2814/0347, 2814/035, B65G 2203/0241, 2203/0258, 2203/0283, 2203/04, G01G 11/-, 13/- & keywords: measure, sense, calculate, freeboard, gap, profile, angle, repose, load, material, bulk, aggregate, heap, mound, rail, wagon, container and like terms.

Applicant/inventor name search in Espacenet, Auspat & IPAustralia internal database.

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
	Documents are listed in the continuation of Box C	

☒ Further documents are listed in the continuation of Box C ☒ See patent family annex

* "A"	Special categories of cited documents: document defining the general state of the art which is not considered to be of particular relevance	"T"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"E"	earlier application or patent but published on or after the international filing date	"X"	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"L"	document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"Y"	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"O"	document referring to an oral disclosure, use, exhibition or other means	"&"	document member of the same patent family
"P"	document published prior to the international filing date but later than the priority date claimed		

Date of the actual completion of the international search
19 June 2018

Date of mailing of the international search report
19 June 2018

Name and mailing address of the ISA/AU

AUSTRALIAN PATENT OFFICE
PO BOX 200, WODEN ACT 2606, AUSTRALIA
Email address: pct@ipaustralia.gov.au

Authorised officer

John Ho
AUSTRALIAN PATENT OFFICE
(ISO 9001 Quality Certified Service)
Telephone No. +61262832329

INTERNATIONAL SEARCH REPORT		International application No.
C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		PCT/AU2018/050469
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	DE 20211181 U1 (ISAM AG) 09 January 2003 Figures 1-14b and abstract	1-70
A	US 5957331 A (MINOR et al.) 28 September 1999 Figures 1-3, column 4 line 38 - column 5 line 30	1-70
A	US 2010/0108188 A1 (CORRENS et al.) 06 May 2010 Figures 1-3 and abstract	1-70
A	US 4629392 A (CAMPBELL et al.) 16 December 1986 Figure 1 and column 8 line 19 - column 10 line 46	1-70
A	US 4659274 A (FRANCE) 21 April 1987 Figures 1-7 and column 5 line 1 - column 7 line 40	1-70
A	WO 2014/197930 A1 (TECHNOLOGICAL RESOURCES PTY LTD) 18 December 2014 Figures 1-12 and page 6 line 30 - page 17 line 7	1-70

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INTERNATIONAL SEARCH REPORT		International application No.	
Information on patent family members		PCT/AU2018/050469	
This Annex lists known patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.			
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		AU 2014280839 B2	24 May 2018
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End of Annex			
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