Generation and Application of Dynamic Lift Kinematics

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Abstract. Performance time is a measure of the time it takes a lift to travel between floors and is crucial to delivering the highest possible handling capacity and lowest passenger waiting times. To calculate performance time and to enable a lift to deliver a comfortable trip leads to a need to understand lift kinematics. Lift kinematics is the study of the motion of a lift car in a shaft without reference to mass or force. When generating lift kinematics, it is normal to consider the travel distance, velocity, acceleration, and jerk; these inputs can be used with well-known equations to determine the time in flight, and a reference speed profile for the lift drive. However, in advanced lift applications, there are additional requirements for the deceleration not to be the same as the acceleration. The jerks may also be different and sometimes it is desirable to change speed part way through a trip. This paper addresses the generation of dynamic lift kinematics to meet these requirements and discusses their application.

1 INTRODUCTION

One method of monitoring a lift is to use an accelerometer to produce a kinematic profile which will provide information on how smooth the journey is. In order to analyse the results of these monitors, reference velocity profiles are needed. Variable speed drives can be programmed to match reference velocity profiles so generating kinematic profiles is useful for driving lifts too. The more control one has over their kinematic profiles, the more accurate the measurements can be, and the more power the dispatcher has over the position of the lift car over time. This paper will demonstrate how an updated model can produce kinematic profiles with fewer limitations than previous models have offered.

In previous papers regarding lift kinematics, equations have been produced which model symmetric profiles [1] and asymmetric profiles [2]. The authors have already detailed the equations in Dynamic extension for Ideal Kinematics [3], this paper will present the same logic but at a higher level and will focus more on the implementation than on the maths.

1.1 Definitions

symmetric profile
the profile of a journey with one target velocity, the same acceleration as deceleration and four identical jerk values. See Fig. 1

asymmetric profile
the profile of a journey with one target velocity but different target acceleration and deceleration or differing jerk values. See Fig. 2

dynamic profile
the profile of a journey with multiple target velocity values. Acceleration and jerk can also vary. See Fig. 3

period
a section of time where the lift is at constant jerk. See Fig. 4

phase
a section of time where the lift is changing from one speed to another including the time it remains at

its final speed. A phase starts and finishes with acceleration of 0 and contains a maximum of four periods. See Fig. 4

journey
a section of time where the lift is changing displacement from when the lift begins to move, to when it reaches its destination. Contains a minimum of two phases. See Fig. 4

1.2 Three types of profile

There are three types of kinematic profile that will be referred to in this paper:

1.2.1 Symmetric Profile

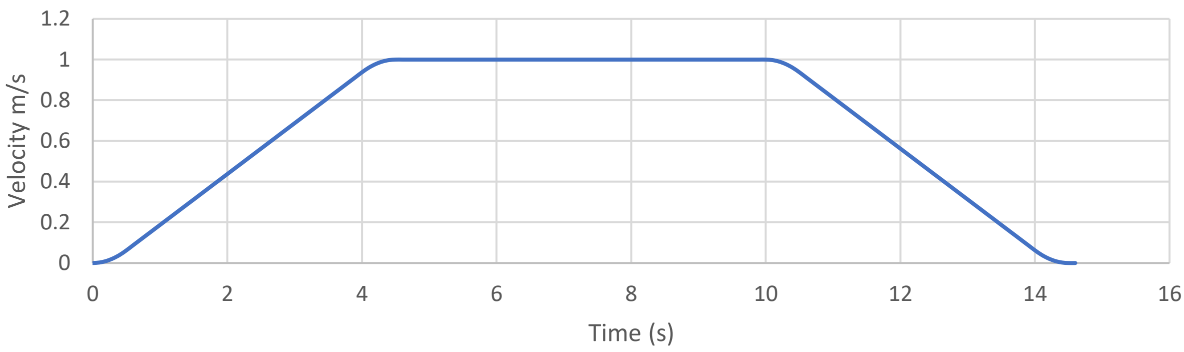

Fig. 1 Symmetric Profile

Fig. 1 shows a profile produced when a symmetric model has been used to plot the kinematic profile of a lift. This assumes that the lift accelerates and decelerates at the same rate which is what most lift systems aim to do in order to provide the smoothest ride quality for the passengers.

The equations for plotting a symmetric profile can be found in 'Ideal Lift Kinematics' by Peters [1].

1.2.2 Asymmetric Profile

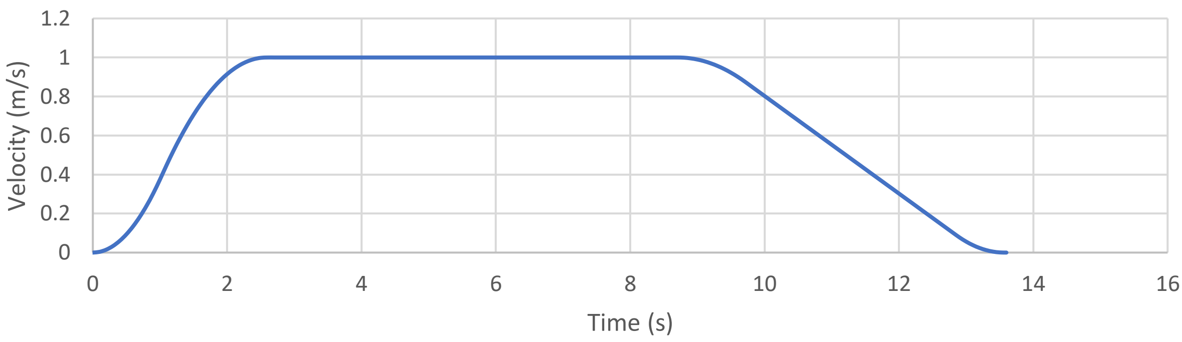

Fig. 2 Asymmetric Profile

Fig. 2 shows a profile when an asymmetric model has been used to plot the kinematic profile of a lift. Like the symmetric profile, this model assumes that there will only be one target velocity, however, it allows for different acceleration and deceleration values as well as differing jerk values.

Some cheaper or older lifts have asymmetric profiles due to the limitations of the drive. By being able to model profiles like this, these asymmetric lift systems can be accurately measured instead of the monitoring system attempting to best fit the data to a symmetric model. The other use of asymmetric modelling is in improving the performance of systems with two cars per shaft. For example, a lower deceleration may be used when the two cars need to be moved closer than allowed by the preferred safety distance. The safety distance between two cars is a function of the car's kinematics. By reducing the car's velocity, the cars can come closer together without compromising safety.

These profiles can be produced using the equations given in 'Quality and quantity of service in lift groups' by Gerstenmeyer [2]. The equations are an extension to the previous ideal lift kinematic equations meaning they can model symmetric and asymmetric equations.

1.2.3 Dynamic Profile

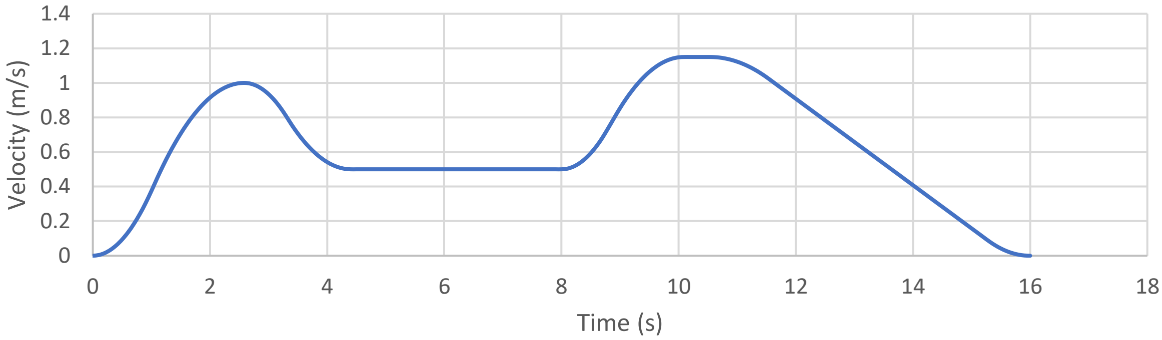

Fig. 3 Dynamic Profile

Fig. 3 shows a profile when a dynamic model has been used to plot the kinematic profile of the lift. This type of profile is occasionally seen in systems with a very long levelling delay where, towards the end of its journey, the lift decelerates to a reduced constant speed which it continues at until it levels with its destination floor. As is the case with lifts following an asymmetric profile, it is useful to monitor these types of systems instead of attempting to best fit them to a symmetric profile.

The dynamic model is also useful in systems with multiple cars. Reducing the velocity of a car at appropriate times can reduce the required safety distance between two cars. In instances where one car is blocking the path of another, travelling at a slower speed to allow more time for the blocking car to be moved away may be more acceptable to passengers than stopping the car completely. Gerstenmeyer states that the resulting increase in performance is particularly valuable to multi-dimensional lift systems with more than two lift cars per shaft. [2].

1.3 Three segments of a profile

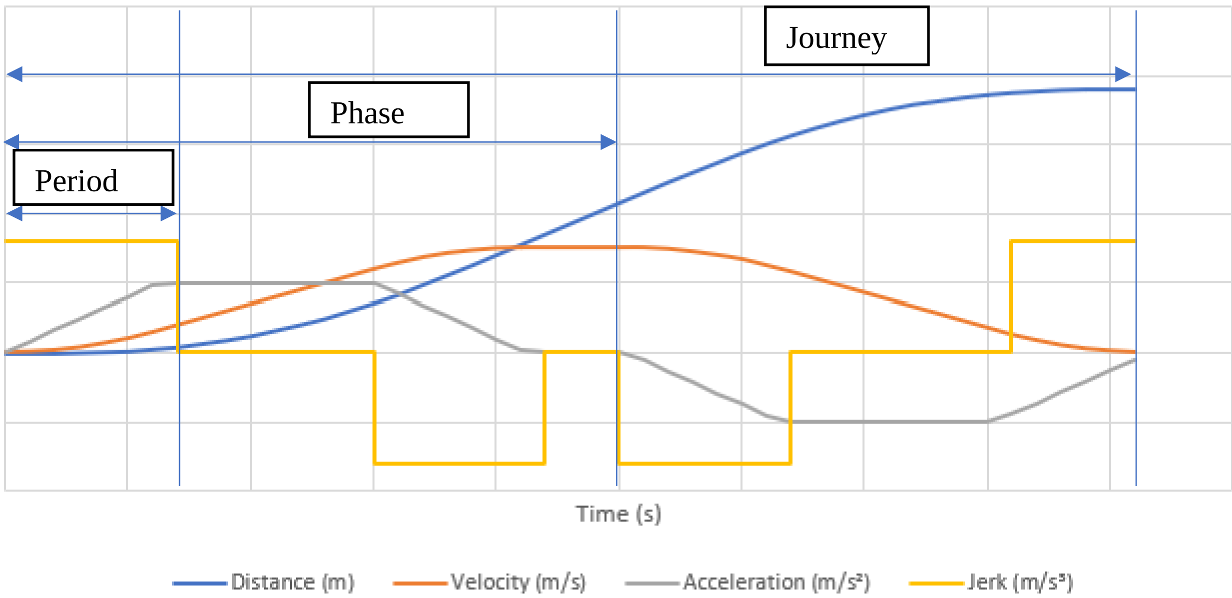

Fig. 4 Period, Phase and Profile labelled profile

Fig. 4 shows the kinematic profile of one symmetric journey. The first period and phase, and the journey are labelled.

2 OVERVIEW OF PREVIOUS RESEARCH

2.1 Previous Work

2.1.1 Analytical Method

Peters provided a set of equations which model the kinematic profile of a symmetric journey [1]. Each journey is divided into seven periods, each with their own set of equations. Each equation does the entire integration including the addition of the starting value at the previous period. This model provides a straightforward set of individual equations which do not approximate each integration like the computation method does. These equations are transparent and functional but very long and lack flexibility. This is also the method described in Annex 2 of Guide D [4].

Gerstenmeyer provided a set of equations which model the kinematic profile of an asymmetric journey [2]. This uses similar logic to the symmetric model however allows four different jerk inputs and two different acceleration values for the two phases involved. Whilst this improves the flexibility of the model, it also makes the equations even longer and harder to implement.

In the cases where a lift cannot reach the inputted velocity or acceleration, Peters proposed alternative models called 'case B' and 'case C' [1], Gerstenmeyer however proposed using the same equations by first reducing the velocity and acceleration to the maximum possible values that can be reached [2].

2.1.2 Computational Method

Computational integration methods include quadrature rule, generalised midpoint rule, adaptive algorithms and extrapolation. These methods use calculations which approximate integration to find the profile values without long equations. This method is far more flexible than the analytical method as it does not rely on period separations. However, the approximation required in the computational method decreases the accuracy of the profile. [5]

2.2 Authors' contribution

The authors have derived an alternative set of equations which map onto the existing equations but allow for more flexible input parameters thus allowing the controller to have more flexibility over the shape of a lift's kinematic profile. The new equations use a combination of analytical and computational techniques and use the Gerstenmeyer method for dealing with invalid input parameters [2].

3 METHOD

As the dynamic model is an extension of the asymmetric model, which is an extension of the symmetric model, the dynamic method should be applicable to all profile models.

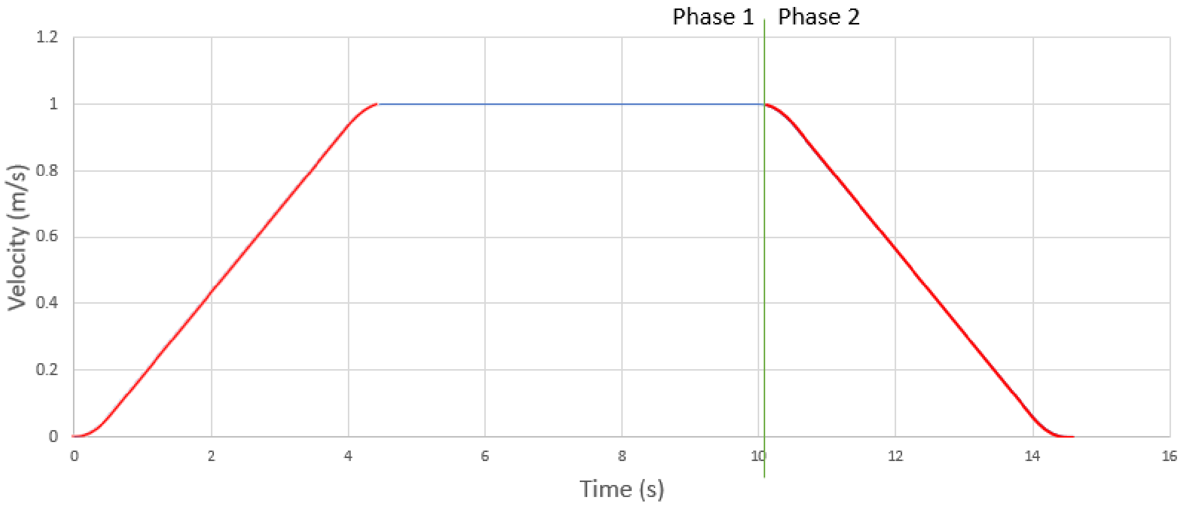

Figure 5 Symmetric phases

Each symmetric profile has two phases and the second phase mirrors part of the first phase. As seen in Figure 5, the two red sections have the same shape in reverse and thus phase 2 can be calculated using the same equation set as phase 1 after some of manipulation.

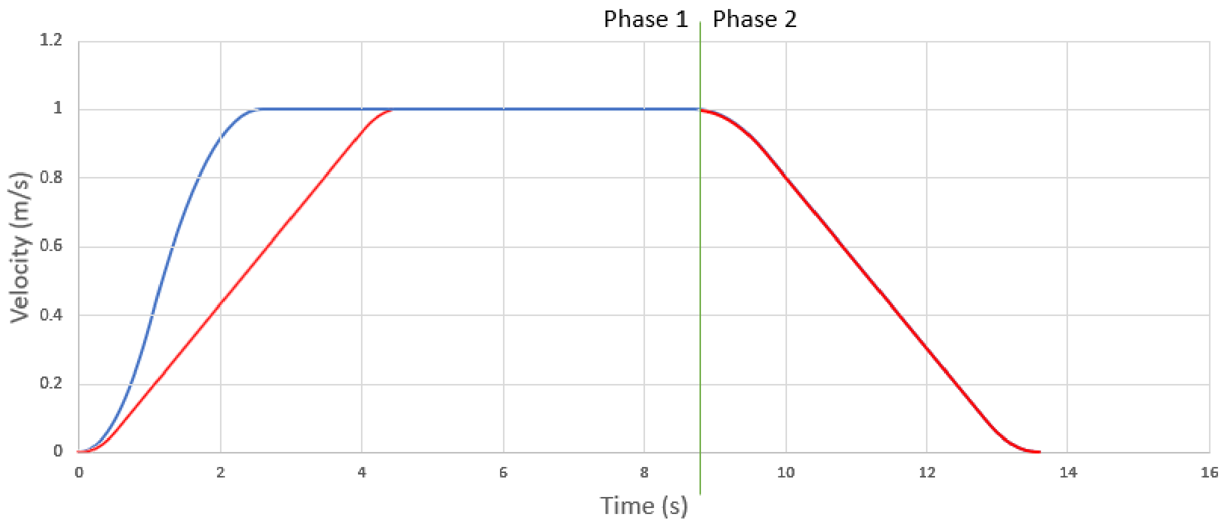

Figure 6 Asymmetric phases

If the acceleration and deceleration do not match, phase 2 is no longer a mirror image of phase 1 however it can still be calculated using the same equation set and then reversed as seen by the first red plot in Figure 6.

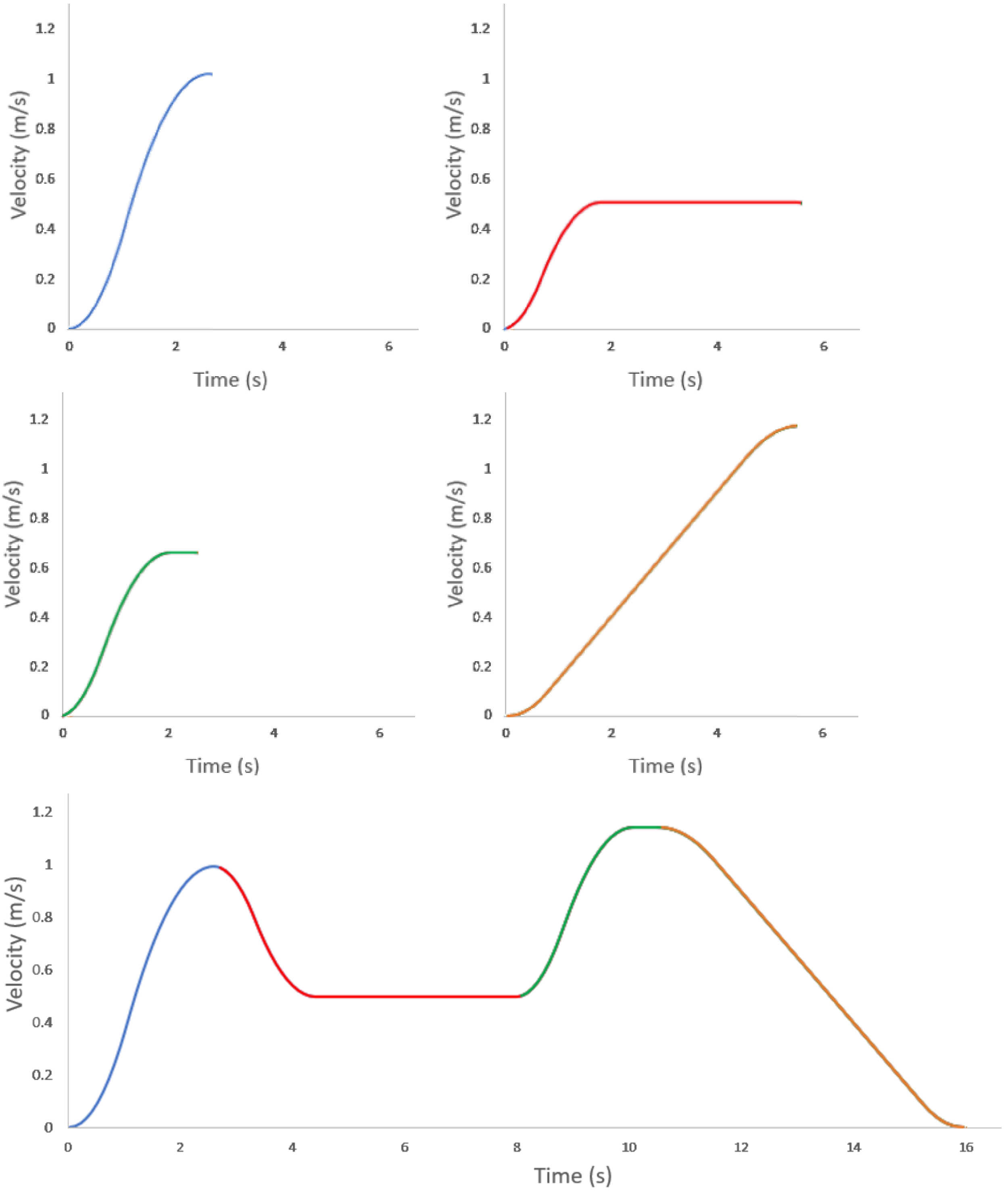

Figure 7 Dynamic phases

In the asymmetric profile, the two phases can be calculated separately and then appended to the same profile later. This is essential for modelling dynamic profiles as seen in Figure 7. Each phase has been plotted on a separate graph and then manipulated and appended to make the final profile.

For more detail on the method, please read "Dynamic extension for Ideal Kinematics" [3] which explains the functionality of the code, provides the necessary equations and shows some examples of the profiles the code generates.

4 QUICKEST STOP FLOOR

4.1 The problem

The quickest stop floor is the next floor a travelling lift can stop at when a new call is made. This is not necessarily the next floor that the lift passes after the call comes in as the car's velocity might be too high to come to a stop in time.

In a symmetric system, this is easy to find with some straightforward equations as seen in [6]. These equations assume condition A, B or C and then reverse the equation for finding the time of max velocity into an equation for the minimum displacement. In the asymmetric model, condition B and C are amended into condition A by reducing the velocity or the acceleration. This means a new approach is needed to find the minimum displacement for asymmetric and dynamic profiles.

4.2 The solution

When using the dynamic model of kinematics, displacement cannot be found using one equation, but instead a function is required which acts recursively to find the displacement at the end of each phase. To find the minimum displacement, this function must be fed with the maximum allowed acceleration and jerk values as well as the lowest possible velocity in the final phase. To find the minimum displacement, the minimum possible velocity must be found.

4.2.1 In period 0

The lift car is currently jerking towards its target acceleration. The acceleration when the call was received is the new target acceleration and the time of the call is set as period 1 and 2 start time. Period 3 start time is then calculated by finding the time taken to reduce the acceleration to zero. The maximum velocity is then calculated by rearranging the period 3 equation.

$$v = a_1\left(p_3 - \frac{a_1(j_1 - j_2)}{-2j_1j_2} - p_0\right) \tag{1}$$

4.2.2 In period 1

The lift car is travelling at a constant acceleration. The time of the call is set as period 2 start time. Period 3 start time is then calculated by finding the time taken to reduce the acceleration to zero. The maximum velocity is then calculated using equation 1.

4.2.3 In period 2

The lift car is currently returning to zero acceleration so the velocity which is currently being targeted is the lowest target velocity possible.

4.2.4 In period 3

The lift car is at constant velocity, so the target velocity is already achieved. The final phase can begin at the same time as the call is sent and the minimum displacement can be found.

5 APPLICATION

5.1 More accurate lift traffic analysis

When modelling lift kinematics, it is currently assumed that the acceleration is the same as the deceleration and that all four jerk values are the same. In a real lift system, due to old or inexpensive mechanics, acceleration and deceleration can vary in a single journey. This can be measured by a car mounted accelerometer and analysed to make a more accurate simulation of an existing system. To use this asymmetric data, equations which model asymmetric lifts must be used.

5.2 Lift systems with two cars per shaft

When two cars share a shaft, the system performance can be improved by giving each car the option to follow a deliberate asymmetric profile thus improving the performance of the system [2].

5.3 Multi-dimensional lift system

For multi-dimensional systems, cars can be given the option to change velocity based on the location of other cars in the system. This can prevent unnecessary stops, improving user experience, and can reduce waiting times, improving performance.

5.4 Improvements to monitoring

Lift performance measurement tools [7] currently try to map the lift's motion to a symmetric profile. Not only will this new model allow monitoring of deliberately asymmetric lifts, data from which will improve simulation inputs, it will also allow for the monitoring of poorly adjusted symmetric lifts thus enhancing maintenance.

6 CONCLUSION

This paper provides a high-level understanding of the dynamic model for plotting kinematic profiles. It explains the basic logic behind splitting a profile into phases and how this can be useful for monitoring, simulating and dispatching.

7 ACKNOWLEDGEMENTS

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BIOGRAPHY

Matthew Appleby is a Software Engineer with Peters Research Ltd and is part of the team working on enhancements to Elevate, elevator traffic analysis and simulation software, and related software projects. Matthew joined Peters Research in 2019 and is studying part-time for a Digital Degree Apprenticeship.

Richard Peters has a degree in Electrical Engineering and a Doctorate for research in Vertical Transportation. He is a director of Peters Research Ltd and a Visiting Professor at the University of Northampton. He has been awarded Fellowship of the Institution of Engineering and Technology, and of the Chartered Institution of Building Services Engineers. Dr Peters is the principal author of Elevate, elevator traffic analysis and simulation software.

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