Performance Validation of an Energy Efficient Elevator Controller

Muhammad Z Hasan, Texas A&M International University; Rainer Fink, Texas A&M University;
Daryl James, Texas A&M University; Jesus Gamboa, Texas A&M International University

Abstract

In smart buildings, measures are being taken to conserve energy without degradation in performance. Elevators are an integral part of many smart, high-rise buildings. To achieve notable energy savings in elevator systems, the authors of this study experimentally tested an algorithm that was developed earlier. Simulation results from an analytical model running the algorithm were encouraging. An elevator controller is capable of saving energy by manipulating elevator speed during operation. Speed is varied based on the difference between load carried and the counterweight. A miniature elevator model was used to carry out the experiments and to collect energy data. The algorithm was tested on both pre-determined and random traffic patterns. Voltage and current samples were collected from the miniature elevator model. The final energy consumption of the proposed variable-speed system was calculated and compared with energy data of a constant-speed system. This proposed method resulted in a 3.715% energy savings for pre-determined traffic pattern and 8.7612% energy savings for random traffic patterns.

Introduction

Recently, energy savings in electrical systems is being explored as one of the prime factors in sustainable development. The use of elevator systems has increased rapidly in urban areas with the growing population. A study of the number of elevators employed in several countries [1] found that Italy had the highest number. In general, any effort towards reducing energy consumption tends to degrade the performance of the system. Thus, there is a necessity to optimize performance and energy with an ideal trade-off. One type of elevator is the traction elevator that has become widely prevalent in recent years. In such systems, the car is suspended by ropes wrapped around a sheave that is driven by an electric motor. A counterweight that equals the mass of the car plus 45% to 50% of the rated load is used to balance the weight of the car. The counterweight is used to ensure that a constant potential energy is maintained in the system [2].

Traction elevators are of two types: 1) geared lifts, typically used in midrise applications, where high speed is not an important factor and a reduction gear is utilized to reduce the speed of the motor; and, 2) gearless lifts, used in high-rise applications, where the sheave is driven directly by the motor eliminating the losses in the gear. In such a case, both motor and sheave rotate at the same speed [2]. The purpose of the counterweight is to maintain sufficient tension in the suspension system. This ensures adequate traction between ropes and drive sheave. The counterweight also maintains a near-constant potential energy level in the whole system, heavily reducing energy consumption [2].

Significant development has been achieved in optimizing elevator controllers in terms of energy efficiency and reducing average waiting and transit time. This involves implementation of artificial intelligence and fuzzy logic in controllers to optimize the service parameters. In this study, the authors dealt with experimental speed manipulation of the elevator, based on load to achieve energy savings and considering its traffic intensity. A trade-off between speed and load torque was proposed, such that their product was constant. This paper includes experimental verification of the proposed idea using a miniature elevator model.

Related Work

Recently, many ideas have been proposed for energy savings in elevator systems. Following is a summary of achievements in single-elevator systems. Effective energy savings can be made through various means such as regenerative energy feedback and loss reduction in order to obtain optimum utilization of energy. Effective energy savings can also be made through energy storage and discharge using capacitors [3] as well as speed manipulation, as considered in this study. A study proved that, for a prolonged duration, a traffic pattern exists that repeats day to day in multi-storied buildings [4]. Based on this fact, a simulation method was developed to analyze the energy consumption of elevators under varying load and traffic patterns. This method was employed to compare energy savings of various drive systems and machinery as well as control systems. This work provided an initial base for the current research on energy consumption of elevator systems. Furthermore, efforts have been reported attempting to reduce waiting and transit time of the elevators. Current research implemented artificial intelligence (AI) and neural networks in elevator group control systems. This involved assigning the elevator cart based on their demand at that instant of time. In these efforts, elevators underwent a period of training with a definite traffic pattern corresponding to the building. This has eased the process of prioritizing the floors based on the requirement during up-peak and down-peak hours of the day. Energy consumption was reduced, even in optimal assignment of an empty cart, based on the need of the hour [5, 6].

Energy conservation can also be made more effective in elevator group systems with intelligent algorithms. These algorithms control all of the lifts in the system, ensuring optimal assignment of each cage to a particular floor [7]. This effort resulted in saving energy by reducing the average number of stops from 1600 to 1400 for a traffic pattern. One recent study involved development of an ant colony algorithm in elevators towards energy conservation during peak traffic flow [8].

There were attempts to strike a balance between energy savings and performance. A recent study reported development of a genetic algorithm towards energy savings in elevators [9]. The algorithm was 23.6% effective in energy conservation. However, the authors reported increased waiting time and service time by 64.9% and 39.5%, respectively. This reveals that energy savings beyond a particular limit may degrade the performance of the elevator. As such, the aim is towards energy savings that does not affect the performance of the system significantly. A study with such simulations was reported [10-12] that used traffic patterns from several other studies [13-15]. Simulation results showed a trade-off between energy savings and travel time. Authors of this current study considered energy conservation in traction elevators driven by electric motors. Normally, traction elevators move at a constant speed, irrespective of the load it carries. This leads to inefficient use of energy. Adjustment of speed based on load is needed for more energy-efficient operation [12].

The Proposed Algorithm, Analytical Model, and Simulation Results

The authors of this study considered energy conservation in traction elevators. With this focus, speed of the elevator was varied, considering the load carried by the elevator cart. In determining the load, the authors considered the counterweight of the elevator and also measured the travel time to estimate its overall performance.

The initial idea was proposed as follows:

1. To achieve maximum possible efficiency, operate the motor at its rated full-load power.
2. To maintain this efficiency, vary the steady speed of the elevator, based on the weight carried, such that the motor operates closer to its rated full-load power [14].

Elevator motor rating, R, is related to its out-of-balance load, B, its rated linear speed, v, and its efficiency, $ç$, as shown in Equation (1) [15]:

$$R = 9.81 \ (B \ v) / (ç) \tag{1}$$

Thus, any change in out-of-balance load gets adjusted by a subsequent variation in the speed of the elevator in order to maintain a fixed efficiency.

3. The upper limit on speed is decided by the following relationship, taking passenger comfort into consideration.

TimeConstant >= 4TimeAccDecel

which is termed as the time-constraint equation. In this equation, TimeConstant is the time the elevator runs at a constant speed, and TimeAccDecel is the time for acceleration or deceleration. The upper limit on speed is found by dividing the distance to travel by the TimeConstant.

This proposed algorithm is referred to as variable-speed algorithm in later parts of this paper. In this algorithm, the lower limit for the elevator speed is the speed at which the elevator would run if the variable-speed algorithm were not applied. Figure 1 shows the diagram representing the traction system considered in the simulation [13]. The maximum load on the elevator was 400 kg with a counter weight of 300 kg. T_M is the motor torque (in N-m), v is the speed of the elevator (in m/s), and r is the radius of the pulley (in m). Equations (2)-(7) represent various relationships used to calculate the energy [13].

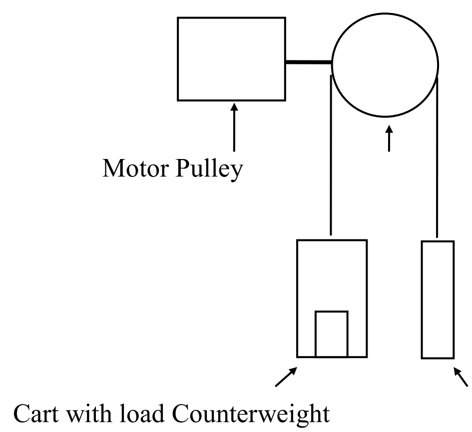

Figure 1. Schematic Representation of the Elevator System

$$LT = (Mu + Mv - Mc)gr \qquad (2)$$

where, LT is the load torque (in N-m) about the center of the motor shaft; Mu is the mass of the load; Mv is the mass of the elevator cart; Mc is the mass of the counterweight; and g is the gravity.

$$v = \text{linear velocity} = 2\pi r \ \text{rps} \qquad (3)$$

$$\Omega M = \text{angular velocity} = 2\pi \ \text{rps} \qquad (4)$$

$$\Omega M, \text{Angular velocity (in radians/second)} = v / r \qquad (5)$$

$$\theta = \text{Angular displacement} = \Omega M \ \text{travel time} \qquad (6)$$

$$E = \text{Energy} = TL \times \Omega M \qquad (7)$$

The following three algorithms were simulated under multiple traffic patterns, and the simulation results were tabulated and compared.

1. *Constant-speed case*: elevator running at a constant speed of 1m/s. This was used as the reference for comparison of energy consumption and travel time.
2. *Speed variation I*: elevator changing its speed based on load but with a fixed acceleration.
3. *Speed variation II*: elevator changing its speed based on the load as well as changing acceleration based on the number of levels moved. (a modified version of *speed variation I*).

Figure 2 show the basic operation of a constant-speed elevator system. According to the calls, the elevator controller determines the direction of movement and satisfies the calls, based on a fixed priority (floors along the direction of movement are given priority). Figure 3 shows the modified version of the algorithm. This algorithm uses the "load on the elevator" to determine the speed of movement and the "number of floors to move" to determine acceleration. The elevator then satisfies the calls similar to the constant-speed case. Figure 3 shows how the calls are satisfied in a five-floor building using this algorithm.

<u>Case 1</u>: Consider the elevator of Figure 1 running in a 10-level building during peak-hour traffic. The three algorithms were simulated. Table 1 shows the simulation results of all the algorithms over the same traffic intensity (peak hour).

This table also shows that the *Speed variation II* algorithm reduces both energy consumption and travel time, as compared to the constant-speed type. Hence, energy savings are achievable at a reduced travel time for peak-hour traffic patterns using *speed variation II.*

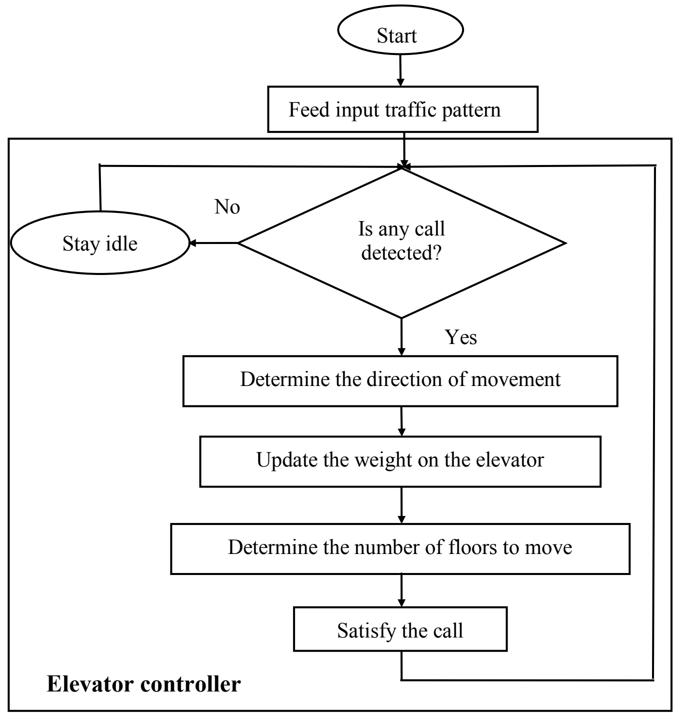

Figure 2. Flow Diagram Elaborating the Algorithm of the Constant-Speed Case

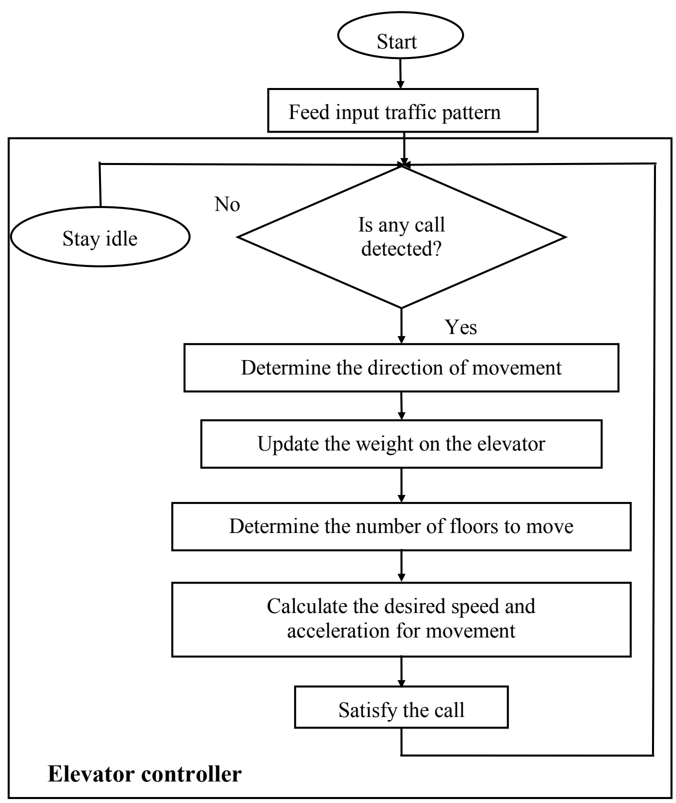

Figure 3. Flow Diagram Elaborating the Algorithm of the Modified Version

Table 1. Simulation Results for 10-Floor Peak-Hour Traffic

	Constant Speed	Speed Variation I	Speed Variation II
Consumption (KJ)	3.45×10^3	3.65×10^3	3.27×10^3
Losses (KJ)	388.83	360.98	394.22
Regeneration (KJ)	-2.88×10^3	-2.92×10^3	-2.81×10^3
Equivalent energy (kJ)	570.1	732.1	465
Total travel time (s)	4.45×10^3	4.21×10^3	4.39×10^3
Efficiency (%)	88.72	90.10	87.96

Case 2: Consider the same elevator with a maximum load of 400 kg, running in a 10-level building during non-peak-hour traffic. The three algorithms were simulated. Table 2 shows the simulation results of all the algorithms over the same traffic intensity (non-peak-hour).

Table 2. Simulation Results for 10-Floor Non-Peak-Hour Traffic

	Constant Speed	Speed Variation I	Speed Variation II
Consumption (KJ)	4.19×10^3	3.96×10^3	3.68×10^3
Losses (KJ)	400.62	337.83	365.00
Regeneration (KJ)	-3.21×10^3	-3.79×10^3	-3.17×10^3
Equivalent energy (kJ)	0.99×10^3	0.18×10^3	0.50×10^3
Total travel time (s)	5.27×10^3	4.88×10^3	4.9761×10^3
Efficiency (%)	90.44	91.46	90.04

For the *speed variation II* algorithm, both energy consumption and travel time were reduced significantly, when compared to the constant-speed type. Hence, energy savings are achievable at a reduced travel time for non-peak hour traffic pattern using *speed variation II*.

Case 3: Consider an additional case of an elevator with a maximum load 400 kg, running in a 20-level building using a non-peak-hour traffic pattern. Table 3 shows the simulation results of all the algorithms over the same traffic intensity (non-peak-hour).

Table 3. Simulation Results for 20-Floor Non-Peak-Hour Traffic

	Constant Speed	Speed Variation I	Speed Variation II
Consumption (KJ)	6.01×10^3	5.99×10^3	5.27×10^3
Losses (KJ)	552.17	418.91	405.86
Regeneration (KJ)	-4.73×10^3	-4.84×10^3	-4.71×10^3
Equivalent energy (kJ)	1.28×10^3	1.14×10^3	0.56×10^3
Total travel time (s)	7.29×10^3	5.86×10^3	5.96×10^3
Efficiency (%)	90.78	93.00	91.90

From Table 3, it is clear that the *speed variation II* algorithm consumed less energy than the other three for a fixed traffic pattern, irrespective of the number of floors in the building. Similar results were obtained from the simulation of a 5-floor building. Thus, from the analyses, the *speed variation II* algorithm produced significant energy savings in both peak and non-peak hours of traffic intensity. Additionally the travel time of the elevator was reduced, thereby enhancing its overall performance.

Miniature Model Implementation

The model system was built for a 5-floor building. It was made up of plywood with open front and back. The motor was mounted on top of the ceiling and the motor shaft was attached to a gear. A chain rotated over this gear as well as two other gears. The chain held the elevator cart on one end and the counter weight on the other. With the rotation of the motor shaft, the chain enabled the cart and the counterweight to move linearly along the vertical axis. Figure 4 shows how the motor was driven by a motor driver, which was also mounted on the ceiling next to the motor. The three-phase induction motor used for this project was driven by driver hardware. The driver was capable of changing the speed of the motor and reading the voltage and current of the motor. The driver could accept commands for motor speed from a host via a serial communication interface. The driver could also send the voltage and current readings of the motor to the host over the same interface. The host was a microcontroller-based system that ran embedded software specifically written for the purpose of running the elevator in single-speed or variable-speed modes of operation.

Figure 4. The Miniature Model Elevator

The embedded software written for the microcontroller was intended to run the elevator motor at a desired speed. The software was required to read the motor current and voltage and convert the data into appropriate units in order to estimate the energy consumption. The software received its input commands from switches that told it to choose either a single-speed or a variable-speed system. For a variable-speed system, the weight applied to the elevator cart was read by the software. Based on this information, the software chose the appropriate speed for the elevator motor (as well as the corresponding frequency for the motor driver) from a look-up table. The software then sent the required command frame to the motor driver. Once the motor started moving, the driver collected motor voltage and current samples as well as sent the samples to the microcontroller software. When the elevator completed a predetermined motion, the microcontroller software uploaded the data to a PC running LabView. The data were stored in a spreadsheet for calculating energy consumption of the elevator.

Analysis and Experimental Results from the Miniature Model

It was decided to collect the motor voltage and current every 100 ms during elevator operation in order to calculate energy consumption. The motor was a three-phase induction motor [16] connected in a Y (wye) configuration. The motor driver manual enlisted the following: phase voltage = Vp (V); phase current = Ip (mA); time difference (sample interval) = t (0.1s, constant); and, motor power factor = PF (0.55 constant). As such, the formulas to be used for exact energy calculation are given here as Equations (8)-(10):

$$\text{Line voltage } V_L \text{ (V)} = 1.73 \bullet Vp \quad (8)$$

$$\text{Line current } I_L \text{ (A)} = Ip / 1000 \quad (9)$$

$$\begin{aligned} \text{Power P (W)} &= 1.73 \bullet V_L \bullet I_L \bullet PF \\ &= 1.73 \bullet 1.73 \bullet Vp \;\; I_L \bullet PF \quad (10) \\ &= 3 \;\; Vp \bullet I_L \bullet PF \end{aligned}$$

where, V_L is line voltage; I_L is line current; and, P is power.

In order to convert W to kw and s to hr, use energy (kW • hr) = power / (1000) • ($t/60^2$). Total energy per trip equals the sum of all energy measurements made during the trip. The overall energy equals the sum of the total energy per trip during a complete traffic pattern. And, as PF was constant, V_p•I_L gave an approximation of the energy consumed, which was assumed to be the case here. Energy data were collected automatically by the control hardware and the software. The elevator was run in both single-speed and variable-speed modes with different weights on the elevator cart. For each trip (start to stop), voltage and current samples were collected by the motor driver. Sampling was carried out at 100-ms intervals. The trips were designated as T_{xy}, where x represented the starting floor and y represented the ending floor. The data table, Table 4, was created by LabView from the collected data items for each trip.

Table 4. Data Items Collected from the Model

Speed system	Weight (lbs)	Trip	Number of voltage samples	Number of current samples
Single	10	T_{12}	120	120
Variable	30	T_{31}	80	80

From these tables, the averages of the voltage and current samples for each trip were calculated with a particular weight on the elevator cart. The average values for voltage and current were multiplied to obtain the power. When trips T_{12} (representing floor 1 to 2) and T_{21} (representing floor 2 to 1) were combined, round trip T_{121} was obtained. This was called a one-level round trip. Other one-level round trips were: T_{232}, T_{343}, and T_{454}. Table 5 shows the power (in milliwatts) consumed for each of these one-level round trips.

Table 5. Average Power Consumed (milliwatts) in Each One-level Round Trip with Zero Pounds on the Cart

Speed System	Trips				
	T_{121}	T_{232}	T_{343}	T_{454}	Average
Single Speed	23.27	23.23	21.44	23.26	22.80
Variable Speed	9.89	9.80	8.75	8.63	9.26

Table 5 reveals a power, P, reduction of 59.36% in favor of the variable-speed mode (for zero pounds on cart). Such tables were created for all possible weights, ranging from 0 pounds to 80 pounds. By multiplying the average power by the trip time, the energy ($E = P\ t$) consumed for that particular trip (in Joules) was obtained. This is shown in Table 6 for 0 pounds. Table 6 also shows an energy reduction of 18.73% in favor of the variable-speed mode.

Table 6. Average Trip-Energy (Joules) for a One-Level Round Trip with Zero Pounds on the Cart

Applied Weight	Speed System	One-level round trips
		Average
0 Pounds on Cart	Single	54.72
	Variable	44.47

Similarly, additional tables were created with the energy data of two different speed systems for all possible loads. From such tables, and for all possible loads on the elevator cart, an energy savings chart was created. Figure 5 shows that (where the x-axis represents the load), a positive value in energy savings represents less energy consumption under the variable-speed algorithm, whereas a negative value represents more energy consumption using the same algorithm. It can be concluded that significant energy savings is possible for 2-level round trips, when the load on the elevator cart is 0, 10, 20, 70, or 80 pounds. Thus, it appears that, for weights larger or smaller than the counterweight, energy savings is significant. However, for weights that are closer to the counterweight (out of balance load was almost zero), there is little or no energy savings. For these loads, the speed chosen was high and the energy consumed was significant under variable-speed operation.

Figures 6-8 present additional energy-savings data for one-, two-, and three-level round trips, respectively, when the load on the elevator cart was 5, 15, 25, 35, 45, 55, 65, and 75 pounds (where the x-axis represents the load). Observation of these figures clearly reveals more instances of energy savings when the elevator is operated under the variable-speed algorithm.

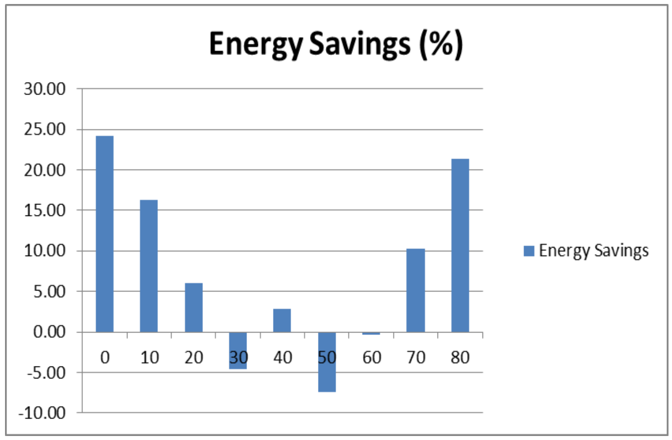

Figure 5. Energy Savings (%) for the Variable-Speed System for Two-Level Round Trips (even weights)

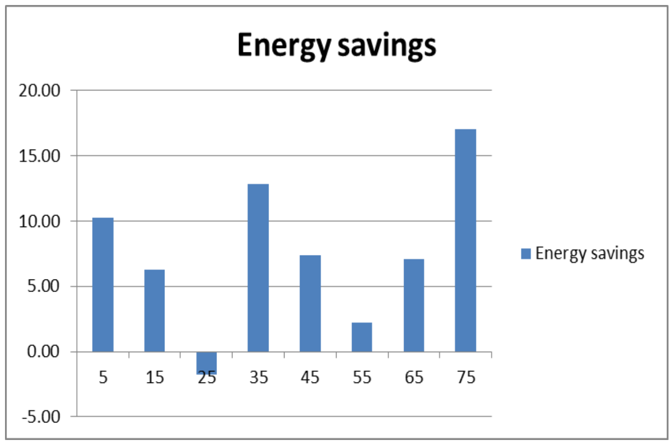

Figure 6. Energy Savings (%) for the Variable-Speed System for One-Level Round Trips (odd weights)

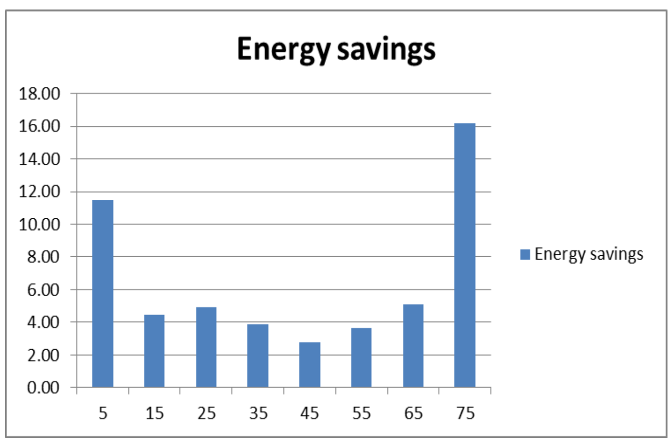

Figure 7. Energy Savings (%) for the Variable-Speed System for Two-Level Round Trips (odd weights)

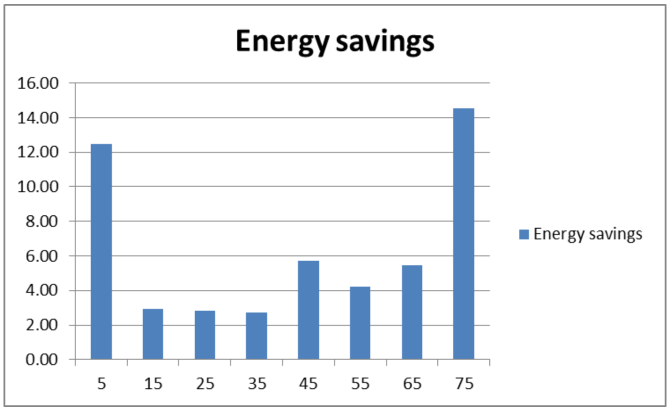

Figure 8. Energy Savings (%) for the Variable-Speed System for Three-Level Round Trips (odd weights)

Synthesized Random-Traffic Energy Data Analysis

The authors created a few random traffic patterns with different sequences of round trips and weights. Energy data were obtained for each single round trip and the added to find the total energy for that pattern. Tables 7 and 8 show two such patterns [15, 17] and the associated energy (in Joules) for the two algorithms (single speed and variable speed). For the first traffic pattern, about 18.48% of the energy was saved under the variable-speed algorithm. However, in the second traffic pattern, there was a loss of energy (4.95%) under the variable-speed algorithm.

Table 7. Energy Comparison of Single Speed and Variable Speed under Random Traffic Pattern 1

Trips	Applied Weight	Average for SS	Average for VS
2 level trip	10 pounds	1130.64	946.31
4 level trip	0 pounds	2319.90	1855.93
3 level trip	80 pounds	1733.24	1413.59
1 level trip	60 pounds	54.12	54.31
	TOTAL	5237.90	4270.15
	Difference (%)		18.48

The authors then created 10 such random traffic patterns. Experiments with these 10 random patterns showed energy savings in nine of the 10 under the variable-speed operation, as shown in Figure 9 (where, the x-axis represents traffic patterns). A positive value represents less energy consumption under the variable-speed algorithm, whereas a negative value represents more energy consumption under the same algorithm.

Table 8. Energy Comparison of Single Speed and Variable Speed under Random Traffic Pattern 2

Trips	Applied Weight	Average for SS	Average for VS
2 level trip	70 pounds	1105.24	991.73
3 level trip	0 pounds	1211.96	1407.13
4 level trip	50 pounds	2240.65	2390.01
1 level trip	20 pounds	54.93	52.13
	TOTAL	4612.78	4841.00
	Difference (%)		-4.95

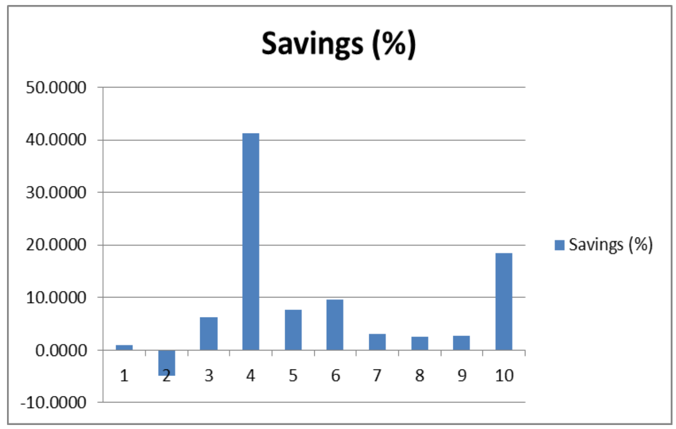

Figure 9. Energy Savings (%) for the Variable-Speed System under Various Random Traffic Patterns

As such, it can be concluded that (in general) the variable -speed operation provides energy savings in such random traffic patterns. The average of these energy savings equaled 8.76%. These results support earlier findings of energy savings with pre-determined traffic (round trips) under the variable-speed mode of elevator operation. Other studies [18-20] were referenced during subsequent analyses. The average energy savings in variable speed for various round trips with different loads was also computed. These round trips were considered to be pre-determined traffic. Table 9 shows the energy savings in percentage for various round trips. The average of these energy savings was 3.72%.

Table 9. Average Energy Savings (%) for the Variable-Speed System for Different Round Trips

1-Level Round trip	2-Level Round trip	3-Level Round trip	4-Level Round trip
7.11	3.71	2.48	1.56

When one compares the data of Figure 9 and the data of Table 9, it appears that the energy savings is higher, in general, for random traffic patterns (between 2% to 40% in Figure 9) than for pre-determined traffic patterns (between 1.5% and 7% in Table 8). This indicates that the variable-speed operation, even with random traffic, is expected to conserve energy. In an earlier study [15], it was shown by simulation that the variable-speed operation of an elevator yielded 5.06% energy savings under peak-hour traffic. The experimental results of this current study from the miniature elevator model support that conclusion. In fact, the average energy savings under random traffic was 8.76% (from Figure 9) in variable-speed operation of the miniature elevator model. This looks promising and should motivate us to undertake further research in this direction.

Comparison of Simulation and Implementation Results

In general, both the simulation and experimental results showed that energy savings are possible in elevator operation under the variable-speed algorithm. The amount of energy savings obtained in simulation was slightly different from the amount of energy savings obtained in the experiment with the miniature model. One reason for this difference may have been the use of a different type of energy form. In simulation, the mechanical energy of the elevator system was considered, whereas in the actual experiment electrical energy was measured. Also, the experimental model was for a 5-floor building, whereas the simulation model was for a 10-floor building. In addition, the actual height of the elevator shaft and the actual weight carried were scaled down in the miniature model with a ratio of 25:1. All of these factors may have led to some differences between simulation and the experiment. Nonetheless, the percentage of electrical energy savings measured in the experiment was higher than the percentage of mechanical energy savings obtained in simulation.

Conclusions

Energy conservation in elevators has gained much importance recently [18-20]. In this paper, the authors presented an algorithm for elevator operation and its verification in order to conserve energy. The focus was to prove earlier simulation results by means of experiments. As such, a miniature elevator model was built for running the elevator in both single-speed and variable-speed modes. Energy data were collected from the model for various traffic patterns (both pre-determined and random). Results showed that the average energy savings under pre-determined traffic was 3.72% and under random traffic was 8.76% in the variable-speed mode (as compared to the single-speed mode). This supports the simulation results published earlier [14]. Possible future work would be to code peak-hour traffic into the elevator controller and run this traffic under the two different modes of operation. The energy data collected from the model under such traffic would be analyzed and compared to verify the effectiveness of the proposed mode of elevator operation during peak traffic.

References

[1] Elevators Employed in Several Countries. (n.d.). Retrieved from http://tian.terc.edu/TIAN_statestandardsAZ.html

[2] Almeida, A. T., Patrão, C., Fong, J., Araújo, R., & Nunes, U. (2010, March). Energy Efficient Elevators and Escalators. Report prepared for ISR-University of Coimbra, Portugal.

[3] Tominaga, S. S., Araki, I., Ikejima, H., Kusuma, H., & Kobayashi, M. (2002). Development of Energy-saving Elevator using Regenerated Power Storage System. *Proceedings of the IEEE Power Conversion Conference*, (pp. 890–895).

[4] Hakala, H., Siikonen, M., Tyni, T., & Ylinen, J. (2012). Energy Efficient Elevators for tall buildings. Retrieved from http://www.kone.com/countries/SiteCollectionDocuments/MP/2001_energy_efficient_elevators_tall.pdf

[5] Zhang, T., Mabu, S., Yu, L., Zhou, J., Zhang, X., & Hirasawa, K. (2009). Energy saving Elevator Supervisory Group Control System with Idle Cage Assignment using Genetic Network Programming. *Proceedings of the ICCAS-SICE International Joint Conference*, (pp. 939–944).

[6] Brand, M., & Nikovski, D. (2004). Optimal Parking in Group Elevator Control. Retrieved from http://www.merl.com.

[7] Dagdelen, U., Bagis, A., & Karaboga, D. (2005). An Efficient Control Method for Elevator Group Control System. *Proceedings of the 2005 international conference on Computational Intelligence and Security* (pp. 1042-1047), Springer-Verlag Berlin Heidelberg.

[8] Jing-Long, Z., Jie, T., Qun, Z., & Jun-fang, L. (2010). Energy saving Scheduling Strategy for Elevator Group Control System Based on Ant Colony Optimization. *Proceedings of the IEEE Y C-ICT*, (pp. 37–40).

[9] Hu, Z., Liu, Y., Su, Q., & Huo, J. (2010). A Multi-Objective Genetic Algorithm Designed for Energy saving of the Elevator System with Complete Information. *Proceedings of the IEEE International Energy Conference*, (pp. 126–130).

[10] Hasan, M. Z., Fink, R., Raj, M., & Baskaran, M. (2012). Assessment and Improvement of Intelligent Controllers for Elevator Energy Efficiency. *Proceedings of the IEEE International Conference on Electro/Information Technology (EIT)*, (pp. 1–7), Indianapolis, Indiana.

[11] Hasan, M. Z., Fink, R., Raj, M., & Baskaran, M. (2016). Evaluation of Intelligent Controllers for Improving Elevator Energy Efficiency. *International Journal for Engineering Research and Innovation*, *7* (2), 5-12.

[12] Hasan, M. Z., Fink, R., Raj, M., Baskaran, M., James, D., & Gamboa, J. (2015). Performance Evaluation of Energy Efficient Intelligent Elevator Controllers. Proceedings of the *IEEE International Conference on Electro/Information Technology*, (pp. 44–49), Naperville, Illinois.

[13] Matlab/Simulink in Drives and Power Electronics. (n.d.). Retrieved from http://www.lgep.supelec.fr/uploads/images/lgep/Mocosem/Cocodi/Pages_perso/gremy/Hebron2009/Practice2_Intro_Simulink.pdf

[14] Cortés, P., Larrañeta, J., & Onieva, L. (2004). Genetic Algorithm for Controllers in Elevator Groups: Analysis and Simulation during Lunch-peak Traffic. *Applied Soft Computing*, *4*, 159-174.

[15] Barney, G. C. (2003). *Elevator Traffic Hand book: Theory and Practice*. Spon Press, London-New York.

[16] Reliance Induction Motors. (n.d.). Retrieved from http://www.reliance.com/prodserv/motgen/b7097_2.htm

[17] Barney, G. C. (2012). Towards Low Carbon Lifts. Retrieved from, http://www.cibseliftsgroup.org/docs/Towards%20Low%20Carbon%20Lifts.pdf

[18] Kiker, P. (2015, June). Study Finds Global Opportunities for Greater Elevator Efficiency. Report prepared for American Council for Energy Efficient Economy (ACEEE).

[19] Lee, S., & Bahn, H. (2005). An Energy-aware Elevator Group Control System. *Proceedings of the 3rd IEEE International Conference on Industrial Informatics (INDIN)*, (pp. 639–643).

[20] Sachs, H., Kwatra, S., & Misuriello, H. (2015, January). Advancing Elevator Energy Efficiency. Research Report A1501 prepared for American Council for Energy Efficient Economy (ACEEE).

MUHAMMAD ZAFRUL HASAN received his BSc in Electrical and Electronic Engineering from Bangladesh University of Engineering and Technology. He received his Master of Electronic Engineering from Eindhoven University of Technology (the Netherlands) under a Philips postgraduate scholarship program. He subsequently held several faculty positions in an engineering college and in a university in Malaysia. He obtained his PhD in Computer Engineering from the New Jersey Institute of Technology. He was awarded the NJIT Hashimoto Fellowship. He taught at Texas A&M University in College Station. He is currently an assistant professor in the School of Engineering at Texas A&M International University. His research interests include the design, implementation, and testing of embedded systems for energy conservation, performance evaluation of computer architectures, and behavioral synthesis and testing of digital systems. Dr. Hasan may be reached at muhammad.hasan@tamiu.edu

RAINER J. FINK received his PhD in Biomedical Engineering in 1995, MS in 1992, and BS in 1988, all from Texas A&M University. He is currently an associate professor in the Department of Engineering Technology and Industrial Distribution, Texas A&M University. He holds several patents in bio-medical devices. His semiconductor test educational efforts have been continuously supported by Texas Instruments (Dallas, TX), Teradyne Inc. (Boston, MA), National Instruments (Austin, TX), National Semiconductor (Santa Clara, CA), and IBM (Austin, TX). His research interests include analog electronics, semiconductor testing, medical device design and testing, product development, and entrepreneurship. Dr. Fink may be reached at fink@tamu.edu

DARYL JAMES received his BS degree in Electronic Systems Engineering Technology in 2013 from Texas A&M University. Mr. James may be reached at daryl.james2010@gmail.com

JESUS GAMBOA received his BS degree in Systems Engineering in 2014 from Texas A&M International University. Mr. Gamboa may be reached at jesus.gamboa@dusty.tamiu.edu