REDUCING THE RELEASE OF ENVIRONMENTAL POLLUTANTS IN RAILWAY TRANSPORTATION USING SLUG LOCOMOTIVES.

Mohammad Sarang [a1], Amin mirza Boroujerdian [b2 *], Amirhosseein Siami [c3]

Abstract

The limited adhesion and force application of the locomotive to the rail surface at the beginning of motion and at low speeds makes it impossible to use the maximum power of the main generator in diesel electric locomotives. This limitation means that there is unused power and current production capacity in the generator at low speeds. This extra or unused power is wasted or, if used improperly, can cause slippage or excessive heating of the motor traction. In addition, limitations in loading and dimensions limit the possibility of supplying more traction force by a single towing unit, which has led to the use of multiple locomotives with Multi Unit (MU) arrangement. Multiple arrangements also create many challenges in operation. The length of stations and the tonnage of demand create limiting factors for using excess power capacity produced. Therefore, on some lines, excess power capacity produced by second or third towing units is not fully utilized while fuel consumption and disproportionate greenhouse gas emissions increase.

The results in this paper showed that in some of the railway transport lines in Iran, instead of using single or double diesel arrangements, single diesel and slug locomotives can be used. Field calculations and experiments showed that the use of slug locomotives can prevent up to 30% of diesel power loss and in addition to increasing the load capacity by about 30%, it can reduce fuel consumption and environmental pollutants by 1 million liters of gas oil and 3 million tons of carbon dioxide per year.

Keywords: Slug Locomotive, Railway, Environment, Adhesion.

[a] Masters student, Road and Transportation Department, Civil & Environmental Engineering School, Tarbiat Modares University, tehran, iran

[b]phd advisor, Faculty of Road and Transportation Department, Civil & Environmental Engineering School, Tarbiat Modares University, tehran, iran

[c] Masters student, Road and Transportation Department, Civil & Environmental Engineering School, Tarbiat Modares University, tehran, iran

[1] *E-mail address*: m.sarang@modares.ac.ir

[2] *E-mail address*: boroujerdian@modares.ac.ir

[3] *E-mail address*: a.siami@modares.ac.ir

Introduction

The connection between the rail and wheel is a vital aspect of railway travel, as it affects a train's ability to accelerate and brake. As the demand for railway transportation grows, trains have become faster with greater acceleration and deceleration capabilities. Despite these advancements, the available friction between steel wheels and rails still limits adhesion (Arias-Cuevas, Li et al. 2011). As demand for railway transportation increases, controlling adhesion force becomes a significant research subject to prevent surface damage on wheel-treads and improve riding quality. The maximum traction coefficient in the rolling direction between the rail and wheel, i.e. the adhesion coefficient, is not significantly affected by the rolling speed up to 300 km/h under dry conditions. However, under wet conditions due to rain or snow, the adhesion coefficient decreases significantly with increasing rolling speed in both field tests and laboratory experiments(Chen, Ban et al. 2002). Efficient railway travel depends on the relationship between the rail and wheel, which affects a train's ability to accelerate and stop. Despite advancements in train speed and braking, the friction between steel wheels and rails still limits adhesion (Oran, Cezayirlioglu, 2021). As demand for railway transportation increases, controlling adhesion force becomes a significant research subject to prevent surface damage on wheel-treads and improve riding quality (Vo, Tieu et al. 2014). The climatic conditions, especially under wet conditions induced by rain or snowfall could cause the loss of adhesion and reduce the coefficient of traction (COT) to a dangerous level. Good adhesion is needed to ensure safe and good traction of train. Poor adhesion between wheel and rail can cause various problems and it could be fatal(Foo, Omar et al. 2018). Wang and colleagues showed in 2018 that the coefficient of wheel/rail adhesion on the ramp path decreases significantly compared to the level track condition under wet and dry conditions. Up and down paths have different wheel/rail adhesion coefficients due to different wheel/rail interactions. In addition, the adhesion coefficient of the down path is less than that of the up path under dry and wet conditions. Oil contamination is an important factor in the behaviour of wheel/rail adhesion. In addition, the ramp path has no significant effect on the wheel/rail adhesion coefficient under oil-free conditions (Wang, Guo et al. 2014). Railway vehicles require adhesion between wheel and rail to operate efficiently, reliably, and economically (Alrasasi, et al., 2021). Low adhesion on the railhead negatively affects railway operation. The maximum power of the main generator in diesel-electric locomotives cannot be used at the start of motion and at low speeds due to the limitation of adhesion and force application from the locomotive to the rail surface. This means that there is unused power and current in the generator at low speeds. This extra or unused power is wasted or if used improperly, it can cause slipping or overheating of the traction motors (Tsadik and Tilahun 2016).

The problem is how to increase the adhesion coefficient of the wheel and rail and prevent the pulling power that is lost due to the low adhesion coefficient?

Literature review

The application of sand is commonly used to improve wheel/rail adhesion. Sand is inexpensive and simple to apply; however, it produces 10 to 100 times more wheel and rail wear. It damages all bearing surfaces of the vehicle and damages the track by contaminating the ballast. Sand should be used only for cases of extreme rail contamination (Jenks 1997). In addition to sandblasting, sanders can also be used to combat low adhesion conditions (often in combination with traction control or wheel slip protection systems) (Arias-Cuevas and Li 2011). Sand is commonly applied to the wheel/rail contact surfaces from train mounted systems to increase adhesion coefficient at low speed (Wang, Guo et al. 2014). In their 2008 paper, Gallardo et al. showed that adding sand causes relatively severe damage to wheels and rails (Gallardo-Hernandez and Lewis 2008). Khalifi and his colleagues proposed the high-pressure air blast solution to the rail surface as a new solution to increase the coefficient of adhesion in 2013. They showed that the air blast with high pressure by the moving train, in addition to removing large rail surface pollutants (such as leaves, debris, dust and surface oxide powders), causes a decrease in the moisture of the wheel and rail surface and a decrease in the moisture of the pollution layer on the rail surface (k.khalifi 2013). Wang and his colleagues proposed the use of special hybrid locomotives and slug machines as solutions to increase the adhesion coefficient of rails and wheels in their article in 2012 (Wang, Palazzolo et al. 2012). A B unit is a type of locomotive unit that usually runs on diesel and does not have a control cab or crew compartment. It must work alongside another paired locomotive with a cab (an A unit) to operate. This type of combination increases the adhesion coefficient of the rail and wheel (Spiryagin, Wu et al. 2018). Hasan and his colleagues showed in 2022 that the development of heavy hydrogen locomotives through simulation increases the power and carrying capacity as well as the adhesion coefficient of rails and wheels. The development of this type of locomotive has environmental benefits as well (Spiryagin, Szanto et al. 2022).

Literature review shows that there has been no adequate research on the lost power of diesel due to the lack of adhesion coefficient between the wheel and rail. Based on this lack of research and the opportunities that heavy hydrogen locomotives create in this regard, this article examines this type of locomotive.

Methodology

The research methodology was designed in 6 steps. These 6 steps start from the analysis of the world's experiences and end with the cost-benefit analysis after the trial operation, shown in Figure 001.

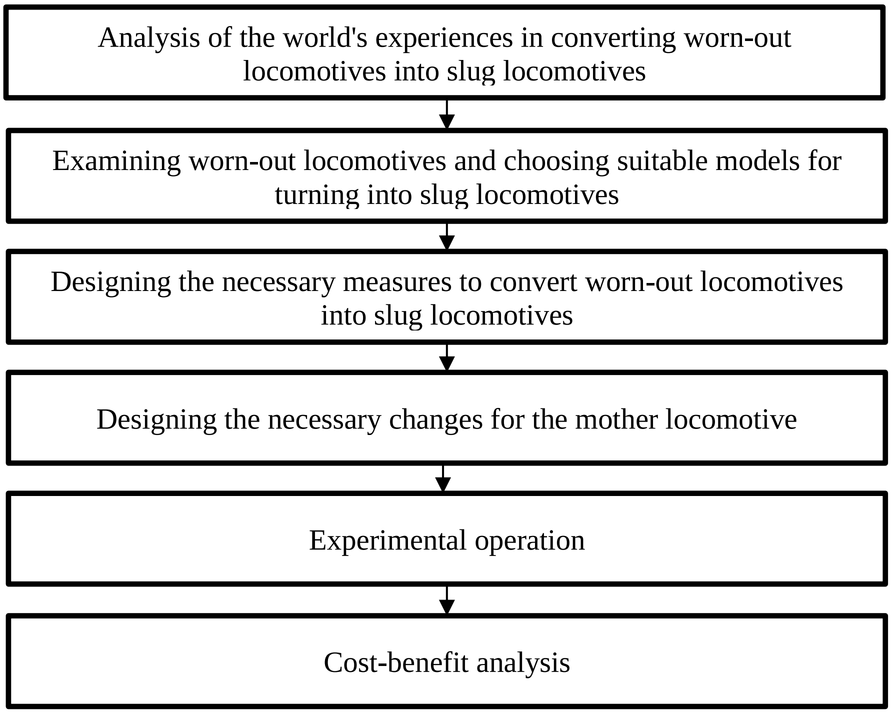

Figure 1: Research Methodology

Case Study

Analysis of the world's experiences

There are experiences for using slug locomotives on the South Australian Railways (SAR), Western Mariland Railway (WMR) in the United States, CSX railway in the United States, TEBC6 slug locomotive on Burlington Northern (BN) railway in the United States, as well as experiences in this regard in Canada, Peru and Brazil. World’s experiences show that the traction motor and control system are the main components of slug locomotives.

Slug locomotives are divided into two categories in terms of operation: 1) Yard slug locomotives is used for maneuvering operations and often has a short body without a cab to increase visibility. 2) Road slug locomotives with the ability to operate on main lines This category of slug locomotives is used as part of a mainline locomotive for traction on main lines and is equipped with a series of equipment to be compatible with this type of operation.

Usually, two locomotives for use as mother and slug should be similar in size, weight, and other characteristics. The slug locomotive is also a function of the mother locomotive in both air and dynamic braking and must be compatible in terms of the braking system. Dynamic braking is not installed on the yard locomotives for operation at low speeds, but is used on road slug locomotives. Also, usually in this category of slug locomotives, the fuel tank is kept to feed the mother locomotives. Slug locomotives are used for maneuvering operations up to 20 kilometers per hour and for mainline slug up to 50 kilometers per hour. For better operation of slug locomotives on main lines, systems have been designed that remove slug from the circuit as speed increases and only enter the circuit to provide the necessary traction force at specific points.

In Figure 2, the primary power generation unit is shown with number 1. This unit is responsible for supplying the energy storage unit, which is shown with number 3. The generated energy is transferred to the independent energy storage unit through the power conversion unit 2. The power conversion unit can include an alternator or rectifiers and similar components. The energy storage unit can include a battery set, a set of capacitors, a compressed air storage system, a flywheel, or a combination of these (Aria Railway Development TORA, 2008).

The wheel and axle assembly, shown with number 5, is equipped with 6 traction motors that act as the driving force. The traction motors can obtain their required energy in three ways:

1- Electrical energy output of the energy storage unit 3

2- Generator or power generation unit 1

3- Combination of the above two methods

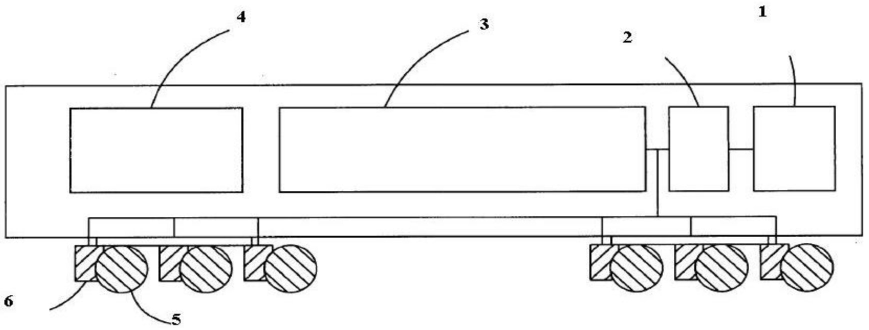

Figure 2: Schematic of a hybrid slug locomotive (Aria Railway Development TORA, 2008)

The diagram shown in Figure 3 shows the different forms of operation of the slug locomotive with the indicated organization. Also, in situations where the slug locomotive is used as an energy storage unit, the motor traction is used to use the braking energy. The operator can choose his desired structure, which is shown in one of the four modes in the figure. In this way, the controller automatically executes the corresponding control algorithm.

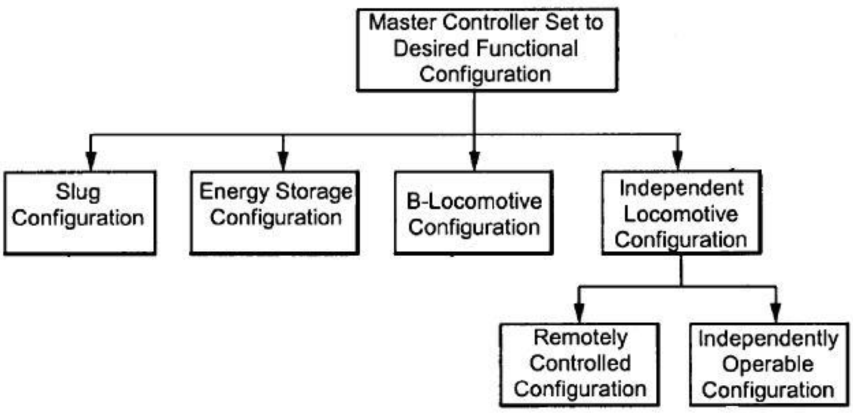

Figure 3: Different forms of operation of the multi-purpose slug locomotive (Aria Railway Development TORA, 2008)

Figure 4 shows the operation diagram of the slug locomotive. Using this algorithm, the controller commands the diesel engine and energy storage unit to shut down. Also, the connection to external power generation networks is cut off. Then, the controller allows the motor traction to be fed by the locomotive or mother locomotives. In braking conditions, the braking energy from the motor traction is stored in the storage network. In addition, the controller is responsible for controlling the current of each traction so that the transferred current for each traction does not exceed the permissible limit. Also, the motor traction current along with its speed is used to determine the traction force used. The motor traction is also monitored for slippage.

The power conversion equipment 2 is responsible for converting the mechanical energy generated by the power generation unit into electrical energy that can be used in the energy storage unit and traction motors. The power generation unit 1 has the ability to supply most of the required power for the locomotive. For this purpose, a suitable fuel tank should be considered for this locomotive, which is shown with number 4. The fuel tank can be located inside or under the locomotive.

To convert a worn-out locomotive to a slug locomotive, if the diesel engine is healthy, it can be preserved on the locomotive and the possibility of dual use of the locomotive as a slug and normal locomotive can be provided according to the conditions. This can effectively reduce engine parts wear and tear and reduce maintenance costs by providing fuel management.

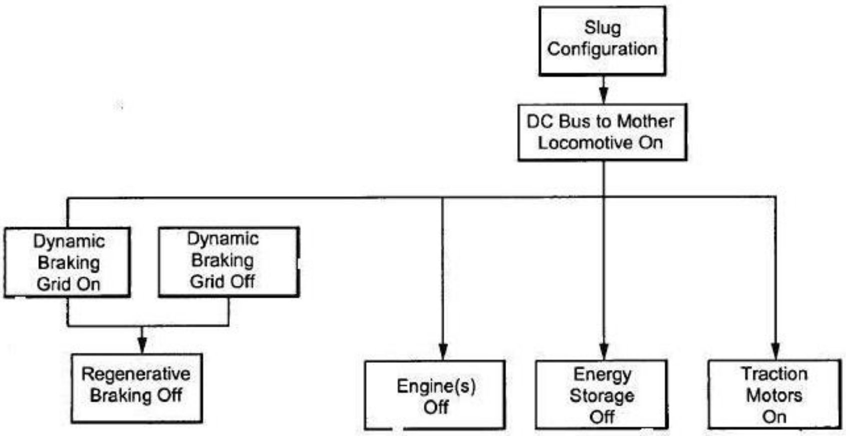

Figure 4: A diagram of the operation of the slug locomotive (Aria Railway Development TORA, 2008)

Examining worn-out locomotives

There are many worn-out locomotives in Iran’s railways. The initial idea was to convert these locomotives into slug locomotives, and this article presents the results of research on converting these locomotives into slug locomotives and its financial and environmental benefits (Karpov, et al., 2021).

In the initial review of the worn-out G12 locomotives on Iran’s railways and worn-out GT26 locomotives with AR10 generators, they were found to be suitable for diagnosis.

Designing the necessary measures

To make a slug locomotive from a worn-out G12, the following steps are envisioned: 1- Complete disassembly of the locomotive. 2- Reconstruction of the chassis and body. 3- Reconstruction of bogies and traction motors. In the process of reconstructing traction motors, they will be upgraded to D77. 4- Making a new drive for traction motor blower (with AC motor powered by generator). 5- Making an axle slip detection system that commands the locomotive’s anti-slip system. 6- Making suitable concrete blocks to weigh down the locomotive. 7- Installing connections for high-pressure electricity, low-pressure electricity, and aforementioned control circuits. 8- Locomotive assembly.

Designing the necessary changes for the mother locomotive

In addition, changes must be made to the mother locomotive to allow it to connect to the slug locomotive, which includes: 1- Relevant connections along with their associated contactors 2- High-pressure and low-pressure feed wiring for slug supply 3- Equipping with additional control systems for controlling the slip of slug traction motors.

Experimental operation

To examine the performance of slug locomotives from the perspective of movement and their effect on cargo transportation, we compare their performance with other methods of cargo transportation on a specific route. Given the speed range for useful use of slug locomotives, routes with long slopes where trains usually travel at low speeds and around continuous speeds are suitable for this purpose. The selected route is Qom-Arak and Arak-Andimeshk, which has the longest slopes and slopes on both routes. The dominant slope of this route is 15 per thousand.

For this purpose, we compare three locomotive arrangements:

1. A single GT26-2 locomotive
2. GT26-2 locomotive with slug locomotive
3. A set of double GT26-2 + G12 locomotives

Table 1: Performance of single locomotive on Arak-Andimeshk route.

Block number	From (km)	To (km)	Time (min)	Fuel Consumption (lit)
20	320.0000	336.1800	17.3625	40.7779
21	336.1800	353.1800	22.6710	173.4212
22	353.1800	373.0400	20.8928	40.1491
23	373.0400	388.1400	31.5271	267.1698
24	388.1400	401.3800	23.9816	221.8647
25	401.3800	419.2000	20.7538	179.9285
26	419.2000	439.4000	30.4261	252.1975
27	439.4000	454.1400	28.3907	261.3991
28	454.1400	467.1000	33.7276	313.8735
29	467.1000	477.6600	20.4941	172.3222
30	477.6600	494.7800	32.6374	301.4336
31	494.7800	507.7200	29.2066	266.2494
32	507.7200	525.7200	41.7748	395.7129
33	525.7200	541.8000	25.4845	234.2380
34	541.8000	554.0200	21.9532	199.3678
35	554.0200	569.7600	21.4382	191.2092
36	569.7600	587.3600	23.8814	207.3921
37	587.3600	601.1400	19.4346	150.0007
38	601.1400	617.1400	24.8151	190.9873
39	617.1400	636.8000	31.8791	221.7558
40	636.8000	649.0400	19.2464	136.8666
41	649.0400	661.6800	36.8477	351.1626
42	661.6800	675.1600	18.8576	171.4125
Sum			**597.6839**	4941
Gross SFC: 7.597 gr/ton.km				

Table 2: Performance of mother and slug locomotive on Arak-Andimeshk route (without increasing load).

Block number	From (km)	To (km)	Time (min)	Fuel Consumption (lit)

20	320.0000	336.1800	17.2818	40.4737
21	336.1800	353.1800	23.2454	180.4734
22	353.1800	373.0400	20.8172	40.0084
23	373.0400	388.1400	31.8924	277.5644
24	388.1400	401.3800	24.9262	230.8156
25	401.3800	419.2000	20.9295	185.4645
26	419.2000	439.4000	31.4081	262.5450
27	439.4000	454.1400	28.7575	267.0340
28	454.1400	467.1000	32.5519	302.3517
29	467.1000	477.6600	19.5593	178.9241
30	477.6600	494.7800	33.5320	309.3809
31	494.7800	507.7200	30.2537	279.4020
32	507.7200	525.7200	42.6670	404.6243
33	525.7200	541.8000	26.4705	243.1576
34	541.8000	554.0200	21.9832	199.4720
35	554.0200	569.7600	21.9506	198.3038
36	569.7600	587.3600	24.4314	214.2508
37	587.3600	601.1400	19.8065	154.8254
38	601.1400	617.1400	25.4852	198.5200
39	617.1400	636.8000	32.7701	229.4569
40	636.8000	649.0400	19.8299	144.0042
41	649.0400	661.6800	34.3598	324.4169
42	661.6800	675.1600	19.3498	175.8119
Sum			**604.2590**	5041.3
Gross SFC: 7.3638 gr/ton.km				

Table 3: Performance of mother and slug locomotive on Arak-Andimeshk route (with load increase).

Block number	From (km)	To (km)	Time (min)	Fuel Consumption (lit)
20	320.0000	336.1800	17.5509	47.2123
21	336.1800	353.1800	28.4953	237.4982
22	353.1800	373.0400	21.0295	44.8103
23	373.0400	388.1400	41.7260	376.1473
24	388.1400	401.3800	32.9650	307.9583
25	401.3800	419.2000	25.9646	237.0267
26	419.2000	439.4000	38.0434	349.6466
27	439.4000	454.1400	37.8917	358.3698
28	454.1400	467.1000	44.1324	412.7172
29	467.1000	477.6600	25.5727	238.4910
30	477.6600	494.7800	46.5191	418.9620
31	494.7800	507.7200	39.7670	377.8377
32	507.7200	525.7200	57.6785	549.7786

33	525.7200	541.8000	35.6511	327.4468
34	541.8000	554.0200	29.2925	268.1424
35	554.0200	569.7600	31.0775	265.3027
36	569.7600	587.3600	31.0887	283.1614
37	587.3600	601.1400	23.8739	202.0119
38	601.1400	617.1400	31.5227	262.7471
39	617.1400	636.8000	42.3043	310.1289
40	636.8000	649.0400	23.8832	188.4928
41	649.0400	661.6800	46.3992	444.1918
42	661.6800	675.1600	24.9851	227.5173
Sum			**777.4145**	6735
Gross SFC: 7.155 gr/ton.km				

Table 4: Performance of double locomotive on Arak-Andimeshk route (with load increase).

Block number	From (km)	To (km)	Time (min)	Fuel Consumption (lit)
20	320.0000	336.1800	17.3167	60.3952
21	336.1800	353.1800	22.6940	261.5040
22	353.1800	373.0400	20.8510	60.1724
23	373.0400	388.1400	31.8296	404.0832
24	388.1400	401.3800	24.1413	336.2875
25	401.3800	419.2000	20.7237	270.6057
26	419.2000	439.4000	30.5778	380.3916
27	439.4000	454.1400	28.0146	389.7186
28	454.1400	467.1000	31.6360	442.0262
29	467.1000	477.6600	19.4943	262.2724
30	477.6600	494.7800	32.5293	451.9238
31	494.7800	507.7200	29.1367	407.0391
32	507.7200	525.7200	41.3388	589.3242
33	525.7200	541.8000	25.5631	353.6775
34	541.8000	554.0200	21.5140	293.5446
35	554.0200	569.7600	21.4568	288.4492
36	569.7600	587.3600	23.8972	312.5274
37	587.3600	601.1400	19.4609	226.3023
38	601.1400	617.1400	24.9369	289.2734
39	617.1400	636.8000	31.9287	334.4496
40	636.8000	649.0400	19.6338	210.7173
41	649.0400	661.6800	33.6058	474.2015
42	661.6800	675.1600	18.8603	257.9616
Sum			**591.1414**	7357
Gross SFC:7.815 gr/ton.km				

By examining the comparative tables 1-4, the following results can be obtained:

1. Using slug when we do not increase the carrying capacity of the train unit is not justified.
2. Using slug increases the carrying capacity of the network with increasing train weight, and if this capacity is measured by ton.km/h criterion, a significant improvement is achieved compared to using a single locomotive. In the above example, this improvement is about 20%. This is while fuel consumption has also improved. In the above example, for transporting 2000 tons of cargo from Arak to Andimeshk, using slug will save about 320 liters of fuel.

Cost-benefit analysis

Table 5: Comparison of fuel consumption, load capacity, and single, double, mother and slug time on the Arak-Andimeshk route.

Locomotive arrangement	Load Weight (ton)	Special Fuel Consumption (SFC) (gr/ton.km)	Fuel Consumption (lit)	Capacity (ton.km/H)	Time Travelled (min)
GT26	1400	7.597	4941	831.1	597.68
GT26 + SLUG	1400	7.3	5401	822.8	604.25
GT26 + SLUG	2000	7.15	6735	989.5	717.515
GT26+G12	2000	7.815	7357	1200.5	591.414

By examining Table 5, the following results can be obtained:

Using slug when the load capacity of the train unit does not increase is not justified. Using slug increases the load capacity in the network by increasing the weight of the train, and if this capacity is measured by ton.km/h criterion, a significant improvement will be achieved compared to using one locomotive. In the above example, this improvement is about 20%. This is while special fuel consumption has also improved. In the above example, for Transporting 2000 tons of cargo from Arak to Andimeshk, using slug will save about 320 liters of fuel.

According to the studies of the Islamic Republic of Iran Railways Research Center, the average fuel consumption per ton-kilometer of freight transport on the railway network is 0.007 liters. Also, 2 grams of carbon dioxide are produced per ton-kilometer of freight transport.

Table 6 shows that supplying one unit of traction force by a locomotive is 58% cheaper than supplying it by a diesel engine.

Table 6: Investment rate for the traction unit for the reconstructed locomotive and slug locomotive

	Increase Traction Force (kgf)	Total Investment ($)	Investment Per Unit Traction Force ($)
G12	28546	30400000	119
Rebuilding G12	28546	1500000	52.55
Slug G12	16414	500000	30.45

In the following cases, this method is the simplest way to convert an old locomotive into scrap:

1. When the old locomotive is still operable as a regular locomotive. In these Conditions, it can be used as scrap to reduce depreciation of the power generation unit, reduce fuel consumption and reduce environmental pollution in special operations (where the traction force is more important than higher power). And in other

conditions where it is possible to operate as a regular locomotive. In these conditions, it is sufficient to provide the possibility of feeding the scrap locomotive by the mother locomotive in two states:

- The ability to operate the scrap locomotive as a follower locomotive and operate the mother and scrap as a double locomotive.
- The ability to operate the above set as a mother and scrap with deactivating the power generation unit in the scrap locomotive and providing the necessary traction power through the mother locomotive. Also, since the power generation unit on the scrap locomotive is still active, it is possible to separate these two sets and operate them separately. Therefore, the required control system must be an upgraded version of the existing control system on the mother locomotive so that in addition to being able to operate two locomotives as MU, it can also deactivate the power generation unit and cut off the main generator current on the scrap locomotive and also provide traction motor feed for scrap locomotives through mother locomotives.

2. The main components required to form a scrap locomotive in an old locomotive such as bogie, brake system and traction motors are healthy and operable. In this case, in addition to basic repairs of these components, with proper installation of a suitable control system for an old locomotive, it will be convertible into a scrap locomotive and will use the existing old power generation unit for supplying required axle load without requiring any lifting.
3. Convert an old locomotive into scrap with minimal changes. In this case, like above, main components of a scrap locomotive such as chassis, bogie, wheel and axle, brake system and traction motors are reconstructed according to their condition.

Analysis and summary

In order to provide greater traction force and subsequently increase portable tonnage, the available coefficient of adhesion cannot be defined as maximum due to its dependence on the geometry and physical specifications of the contact surface between the wheel and rail and weather conditions. One simple way to increase traction is to increase the weight of the locomotive. However, it should be noted that the increase in locomotive weight is limited by the maximum axle load. Generally, locomotives are designed to use high adhesion force to maximize their axle load within the permissible maximum axle load of the lines. It should be noted that the use of advanced control systems to increase reliable adhesion only creates a chance for greater traction force, and the condition for achieving this is the ability of the locomotive and especially its traction motors to provide this additional traction force. In other words, if modifying the control system is not accompanied by modifying the traction motors or if the traction motors do not have a greater capacity than what they are currently using, changing the control system does not make much sense. Therefore, considering the aforementioned, one suitable solution for increasing portable tonnage is only possible by increasing the number of driving axles in locomotives, a method that is currently being implemented by increasing the number of locomotives. However, increasing the number of driving axles in a locomotive with a fixed power supply is another solution. If it is possible to supply it through the main generator, increasing the number of driving axles provides the possibility of absorbing more current and providing more torque and traction force through a greater number of traction units. However, due to limitations caused by locomotive behavior in curves and design issues, it is not possible to increase the number of axles in a locomotive while maintaining its current dimensions. Therefore, according to the definitions provided for freight locomotives, freight locomotives provide the possibility of using old locomotives and refurbishing them with minimal cost, by increasing the number of axles and subsequently the traction units, and in fact increasing the effective weight in calculating the traction force, providing the opportunity to use the maximum current produced by the main generator and increasing the traction force.

By removing the power generation systems from the old locomotives, a special locomotive (Slug Locomotive) is obtained that only has traction motor systems. This method has the ability to improve up to 30% of the load-carrying capacity without being limited by the axle load, dimensions and maximum allowable current of the traction motors. This additional pulling force is added to the circuit at low speeds and when passing steep and long slopes and is removed from the system at high speeds. Increasing the number of traction axles in slug locomotives increases the pulling and braking force. Therefore, in slug locomotives with power distribution on additional axles, it is possible to create more pulling force.

The advantages of using slug locomotives can be introduced as follows: • Providing the possibility of operating the locomotive at full power at low speeds. • Using the full current capacity of the main generator of the locomotive in additional axes to provide more traction force without slipping. • Economically, a pair of mother and slug locomotives have lower operating costs than a pair of locomotives capable of carrying similar tonnage, such as fuel and maintenance costs. • Reducing air pollution. • Reducing noise pollution. • Ability to carry more load at low speeds. • Increasing effective weight in calculating traction force (increasing the number of driving axles). • One of the direct effects of this plan is to increase the tonnage that can be carried by a train by the same number of locomotives. • Slug locomotive has 50% of the cost of a new locomotive. • Their maintenance costs are significantly lower than those of ordinary locomotives due to the absence of a diesel engine and main generator. • Increasing consumable material capacities such as fuel, water, sand and oil by more than three times the capacity of a locomotive.

Their side applications are as follows: • Maintaining the fuel tank in them to feed the mother locomotives on long routes. • Installation of dynamic equipment. • The location of the GNG tank for gas locomotives. • Convert it to a hopper car. • Convert it to a steam generator car in passenger trains. • Ability to operate it as a hybrid locomotive. • Equipping the cabin with the ability to control the mother and slug set.

In the operation of slug locomotives on main lines, we face some limitations, the most prominent of which is speed. The slug locomotive set must have the ability to provide adequate traction force. Because in this set, only the mother locomotive has the ability to generate power for both locomotives, the main generator in the mother locomotive must produce its maximum electrical energy. The maximum speed for the slug locomotive set is 40 kilometers per hour. To solve this problem, slug locomotives are planned in such a way that after reaching the maximum speed, the traction motors are placed off-line in the circuit and do not completely shut down. The off-line placement of the traction motor prevents damage to the brushes and commutator. In these conditions, a load of about 300-100 amps passes through them and thus the brushes of the traction motor provide the required carbon film on the surface of the commutator. This film plays a vital role for traction motors in terms of increasing conductivity properties and preventing the formation of electric arcs between brushes and damage to the commutator. After the speed drops below 40 kilometers per hour, they are planned to be restarted. The lower the speed, the more pulling force is created.

Conclusion

Based on the literature studies, the presented study shown in this article, it can be concluded that:

- The slug locomotive increases the wheel-rail adhesion coefficient. This increase in adhesion prevents the loss of diesel mother traction force.
- The slug locomotive increases the traction force by 30%. This increase in traction force increases the towing capacity by the same amount.
- For loads of the same weight, the slug locomotive reduces fuel consumption by 10% compared to double diesel.
- Despite the advantages of slug locomotives, their use is recommended under special conditions. These conditions include 1) Freight routes where station length limits the use of double diesel. 2) Freight routes that have high slopes and are overcome by double diesel. 3) Freight routes that have large tunnels and ventilation of these tunnels is problematic. 4) Station maneuvering operations
- The use of slug locomotives reduces environmental pollutants, especially inside stations.
- Studies in Iran show that 1500 million ton-kilometers of freight are transported under special conditions each year. In these conditions, the use of slug locomotives reduces fuel consumption by about one million liters per year.
- The use of slug locomotives in these conditions prevents the emission of about

three million tons of carbon dioxide per year.

References

Arias-Cuevas, O. and Z. Li (2011). "Field investigations into the adhesion recovery in leaf-contaminated wheel–rail contacts with locomotive sanders." Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit **225**(5)-443 : .456

Arias-Cuevas, O., et al. (2011). "A laboratory investigation on the influence of the particle size and slip during sanding on the adhesion and wear in the wheel–rail contact." Wear **271**(1-2): 14-24.

A. R. D. TORA, "Slug Locomotive Report," 2008, Iran.

Alrasasi, M. N. M., Alismail, H. M., Alabbad, F. A. A., Justaniah, H. M. S., Alanazi, N. A. S., Alhamoud, A. A. A., Almasabi, A. A., Alanazi, N. R., & Alrashed, S. A. (2021). *An Overview on Road Traffic Accident Management Approach*. *International Journal of Pharmaceutical Research and Allied Sciences*, *10*(1), 34-37.

Chen, H., et al. (2002). "Adhesion between rail/wheel under water lubricated contact." Wear **253**(1-2): 75-81.

Foo, C., et al. (2018). A review on recent wheel/rail interface friction management. Journal of Physics: Conference Series, IOP Publishing.

Gallardo-Hernandez, E. A. and R. Lewis (2008" .(Twin disc assessment of wheel/rail adhesion." Wear **265**(9-10): 1309-1316.

Jenks, C. (1997). "Improved methods for increasing wheel/rail adhesion in the presence of natural contaminants." Transit co-operative research program, Research Results Digest(17).

Karpov, V. Y., Medvedev, I. N., Komarov, M. N., Dorontsev, A. V., Kumantsova, E. S., & Mikhailova, O. D. (2021). Possibilities of Students' Health Improvement through Physical Training in the Aquatic Environment. *Journal of Biochemical Technology, 12*(4), 67-71. .

k.khalifi, m. d., m.elyasi, m.abbasi (2013). practical solutions to increase the adhesion coefficient of locomotives in the Islamic Republic of Iran railway. 21st annual international conference of mechanical engineering of Iran.

Oran IB, Cezayirlioglu HR. AI - Robotic Applications in Logistics Industry and Savings Calculation. J Organ Behav Res. 2021;6(1):148-65.

Spiryagin, M., et al. (2022). Advanced Modelling and Performance Evaluation of Hydrogen-Powered Heavy Haul Locomotive. ASME/IEEE Joint Rail Conference, American Society of Mechanical Engineers.

Spiryagin, M., et al. (2018). "Comparison of locomotive energy storage systems for heavy-haul operation." International Journal of Rail Transportation **6**(1): 1-15.

Tsadik, M. G. and D. Tilahun (2016). "Extent of adhesion losses in the wheel-rail contact under contaminated conditions." Zede Journal **34**: 36-46.

Vo, K., et al. (2014). "A 3D dynamic model to investigate wheel–rail contact under high and low adhesion." International Journal of Mechanical Sciences **85**: 63-75.

Wang, W., et al. (2014). "Experimental investigation of adhesion coefficient of wheel/rail under the track ramp conditions." Proceedings of the Institution of Mechanical Engineers, Part J: Journal of Engineering Tribology **228**(7): 808-815.

Wang, Z., et al. (2012). "Hybrid train power with diesel locomotive and slug car–based flywheels for NOx and fuel reduction." Journal of Energy Engineering **138**(4): 215-236.