Concept for autonomous shunting with an intelligent and self-actuating freight wagon

Matthias Blumenschein, Daniela Wilbring, Katharina Babilon and Bernd D. Schmidt

FH Aachen University of Applied Sciences

Abstract

The increasing digitalisation in the industry requires the railway sector to modernise its systems concerning digitalisation and automation and not only catch up with today's standards but set new touchstones. This enables the rail freight transport to be leading in the freight transport sector. One approach is to establish intelligent and autonomous freight wagons.

At the University of Applied Sciences Aachen the projects wagon 4.0 and Shunting Assistant & Monitoring Interface for Autonomous Rail Application (SAMIRA) are running in the field of rail vehicle technology. Both projects deal with the digitalisation of freight wagons for the automation and autonomy of rail freight traffic. This paper describes how a basis for autonomous freight wagons can be achieved.

1 Introduction

The Aachen University of Applied Sciences is currently partner in two projects concerning rail freight transport. On the one hand there is the project "New Electronic and Communication Systems for the Intelligent Networked Freight Wagon" (short Wagon 4.0). In that project the freight wagon is being equipped for the Industry 4.0. In the other project called "Shunting Assistant and Monitoring Interface for Autonomous Rail Application" (short SAMIRA) a rear-view camera for freight trains is being developed, which is supposed to make shunting operations easier and more efficient. In this paper, a promising solution on how to merge both projects will be presented as well as its benefits and a possible usecase.

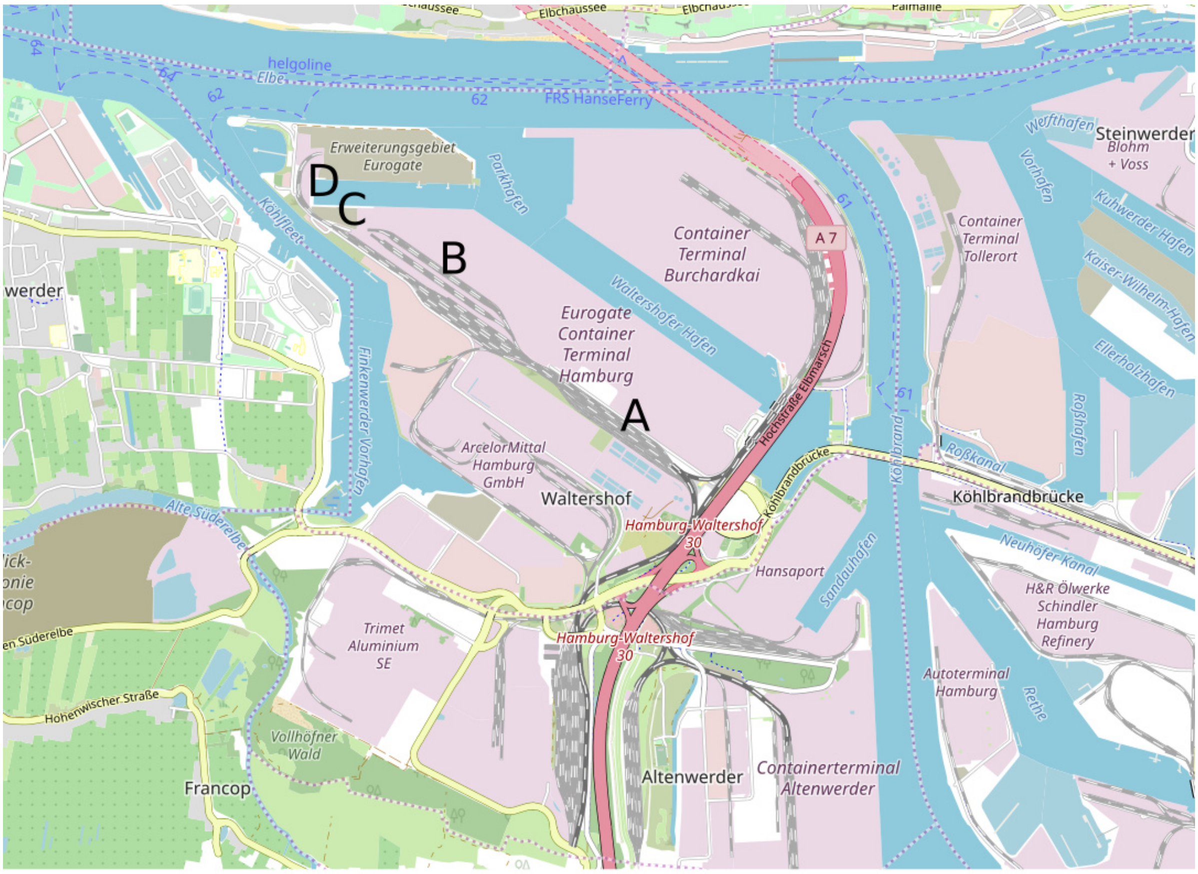

Figure 1. Port of Hamburg

In this case, the sea freight port of Hamburg is considered. In 2019, around 9.3 million standard containers and approx. 42.8 million tonnes of liquid goods, suction goods, grab goods and general cargo goods were handled there. This makes Hamburg the third largest port in Europe in terms of container handling after Rotterdam and Antwerp. [1, 2]

More than 50 transhipment facilities operate on an area of over 71 square kilometres. Goods and containers are transported to the continental Europe by truck, inland waterway and rail. The port rail infrastructure has a track length of 287 km with 762 switches. [1, 3]

The operator Hamburg Port Authority (HPA) uses the software transPORT rail for the disposition of the good transport. This is a traffic management system that provides an interface for the exchange of goods and data.

2 Handling of a freight wagon in the port of Hamburg

When a train enters the port area, it is registered in the harbour-management system TransPORT rail by the dispatching department. The dispatcher manages the unloading and loading timeslots of the freight train. When the train arrives at the habour it is taken over by the port logistics at the siding and brought to the shunting yard. If necessary, the freight wagons are sorted according to their load in the shunting yard (figure 1, point A). New wagon groups are put together. Frequent repositioning (saw tooth movementsof the shunting locomotive and coupling is necessary to resort the freight train (table 1, step 1). Container wagons and the locomotive are coupled (screw coupling and compressed air coupling) and a brake test is carried out. Afterwards the trains drives to the container terminal (figure 1, point B). At this place, the wagons are unloaded and loaded with a gantry crane. After unloading the wagons (table 1, step 2), an inspection of the train for damage must be carried out (table 1, step 3). Then the securing pins and bolts on the container wagon are adjusted by an employee according to the container size so that the train can be loaded again (table 1, step 4). The loaded wagons are brought back to the shunting yard (figure 1, point A). A brake test must be carried out during re-coupling with the mainline locomaotive (table 1, step 5) before leaving the port of Hamburg.

With liquid goods, the process is a bit different. Here approx. 8 wagons can be loaded and unloaded at the same time. For this purpose the train is brought to a groupe of shunting tracks upstream of the loading station (figure 1, point C). There the train is divided into sections which are brought to the loading station (figure 1, point D) one after the other by a shunting locomotive. After loading of unloading, the wagons are brought back to the group of shunting tracks in front of the loading station.

The following table summarizes the duration of the respective work steps. Without waiting time a train spends from arrival to departure in the port a minimum time of approximately 4 hours at the harbour.

Table 1: Duration of processes

Step	Description	Duration ops
1	Arrival and if necessarry splitup	00:30
2	Unloading (manual operated stackers or crane)	00:45
3	Inspection of the train	00:30
4	Setting bolts and loading (manual operated stackers or crane)	00:45
5	Assembly and brake test	01:30
	Sum	04:00

3 Wagon 4.0

The relevance of of manual activities for freight trains in the seaport area have been shown above. Using the Wagon 4.0 this expenditure can be counteracted. The project „New Electronic and Communication Systems for the Intelligent Networked Freight Wagon" is intended to be profitable for all participants, from the loading station via the train preparation to the main section and back. Equipped with a power supply, on-board electronics, actuators, sensors and a drive system, Wagon 4.0 is part of the distribution logistics at the depot and the automatic train formation in the siding. In the following sections, these points will be clarified in relation to the port of Hamburg.

The Wagon 4.0 has a modular structure. Apart from the first stage, all stages are optional and can be extended as required. A possible structure is shown in Figure 2.

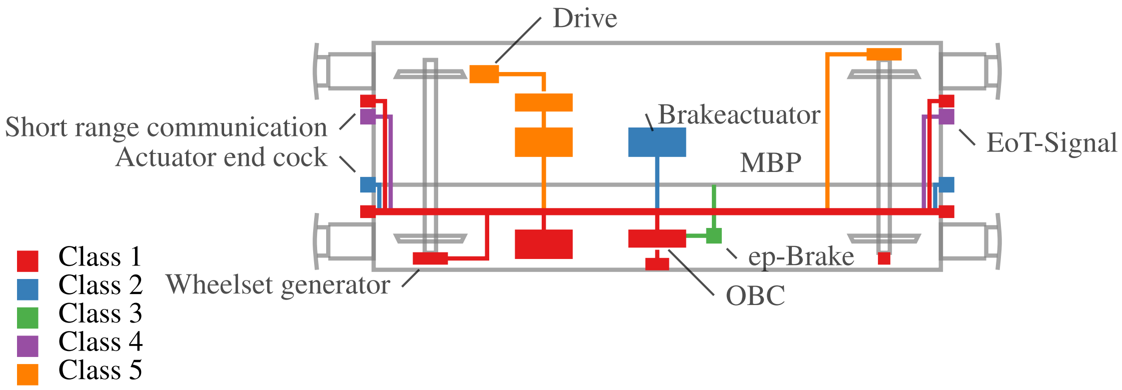

Figure 2. Wagon 4.0 in five stages

In the first stage of expansion, the previous freight wagon will be converted into a Wagon 4.0 equipped with electricity, telematics and data networking, which is not active by itself, but offers all the necessary interfaces for setting up the required sensors and actuators. The power supply is established via a $24VDC$ network according to VDI 5905. The battery is supplied by an axle cover generator. The on-board computer (OBC) as well as attached sensors and actuators are connected to the battery. [4]

In the second expansion stage, the operating technology is automated. Possible options are, for example, actuators for end stop valves, handbrake and braking mode. In this way, part of the brake operation can be automated to such an extent that the brake type can be set on the basis of other wagons in the train, weight and braking capability. It is also possible to implement the parking brake. Sensors at the end points are then required for monitoring. The possibility for automatic brake calculation and brake testing is created by appropriate actuators.

These also offer the first step towards automation of rail freight traffic. Shortening the train preparation time will also free up capacity in the infrastructure and among staff and increase the effectiveness of rail freight traffic.

The third stage of expansion consists of an ep-assist brake. Ep-Assist means speeding up brake application be avoiding latency due to speed of air and using electric signals instead. It is a prestage of ep-braking and provides shorter braking distances and less wear on brake pads and wheel, since braking is synchronized over the entire train length. Ep-Assist needs only a main break-pipe (MBP), a main reservoir pipe is not required.

In the fourth expansion stage, an automatic end of train signal follows. A technically secured train end enables a train integrity check and thus also ETCS Level 3, which until now appears unattainable for freight trains. As a fall-back level, the necessary end-of-train signal will be replaced by an electric light in this expansion stage. Compared to stages one and two, this stage is not as complex in terms of cabling, but requires a safe control system.

In a fifth expansion stage, the system will be equipped with a shunting drive. The drive enables the wagon to move independently or in a guided manner so that it cannot only move itself but also shunt another unbraked wagon without a drive. This allows shunting operations of wagons on a factory site without a shunting locomotive or robot. The already presented method of semi-automatic siding and letterbox operation is also possible in this way. [5]

Considering all possible stages, power supply and communication are the most important. The drive provides independent movement in the port area. The power supply opens up further features such as SAMIRA.

4 SAMIRA

SAMIRA aims to boost the digitalisation of the last mile in order to reduce the needed resources and it also will be a basis for future autonomous rail operations. It can be understood as an advanced driver assistance system (ADAS) and it basically consists of a sensor box attached to both ends of the train and artificial intelligence (AI) in order to monitor the tracks and the train's environment. Sensors and AI support humans and enhance the operational safety.

It can be observed that nowadays shunting operations are extremely expensive [6]. This is due to the fact that shunting is currently carried out by two workers: the driver in the locomotive cabin and one worker at the end of the train monitoring the environment and giving instructions to the driver. This results in very high personnel costs and the job on the platform of the last wagon is considered to be very dangerous and uncomfortable. Furthermore, radio communication over such long distances especially in shunting yards cannot be considered secure. In this case, it has to be taken into account that the skill shortage in railways is even increasing the dilemma. Alternatively, the locomotive driver controls the freight train with a remote control from the last wagon while monitoring the environment. However, this causes long and time intensive walks when changing the shunting direction.

One approach to counteract the issues mentioned above is automation as the rail sector and in particular shunting operations are well suited for a high degree of automation since many operational rules are coded in books issued by safety boards or railway undertakings. In fact, assistance and automation are vastly desirable since they increase the operational safety, counteract skill shortage in the rail sector, raise the job's attractiveness by shifting the workplace from the last wagon into the locomotive and lead to time and cost saving.

The main advantage of SAMIRA is that it enables the locomotive driver to run on sight without the help of the second worker. In order to do so and be an efficient ADAS, SAMIRA has to take over the following tasks. First, a live video stream from the end of the freight train is sent to a human machine interface (HMI) inside the locomotive. Second, obstacles (humans, vehicles, goods, ...) inside and close to the clearance gauge are detected and classified automatically in a range of 100 m in front of the train and then highlighted in the video stream and warn the locomotive driver in order to increase the operational safety. Therefore, it is necessary to detect the tracks and the switch positions ahead in order to know exactly where the clearance gauge is located and which obstacles are relevant. Furthermore, the system determines the train's accurate position in order to allow the fusion of sensors located at different places (onboard and wayside sensors) in a global coordinate system. Beside that, the control room obtains an overview of all shunting vehicles and is able to ensure the operational safety. Its fifth task is the recommendation of the ideal speed to drive. This is done by combining the information of detected velocity signs next to the tracks in order to know the maximum allowed velocity and by checking the track vacancy ahead.

SAMIRA consists of four main modules which communicate via a wireless multipath mesh network (WMMN) as depicted in figure 3. The WMMN is characterized by high data transfer rate, flexibility, stability and low latency since it can use multiple sources for data transfer (ethernet, optical fibre, directional radio, mobile radio 4G/5G) during the same time and thus enables real time data transfer. Using different channels it is possible to establish a comprehensive network over the whole railway yard in order to prevent disconnection and data loss.

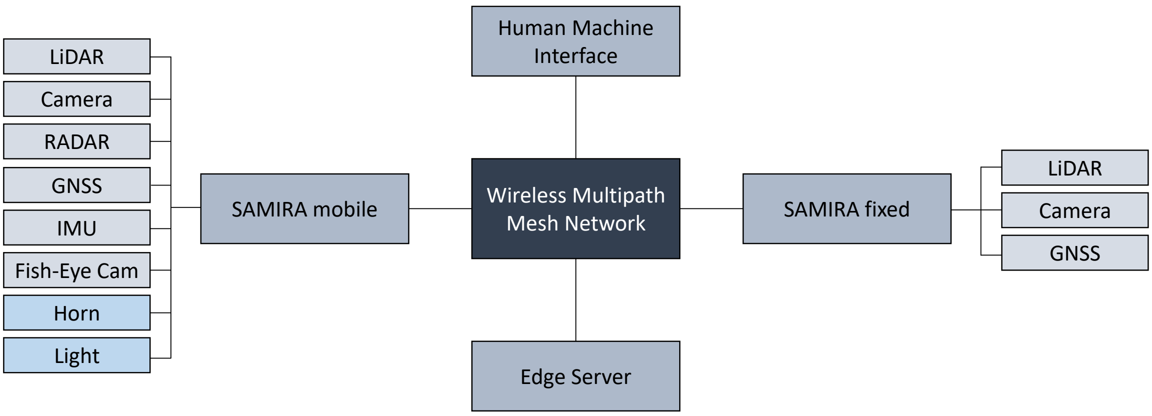

Figure 3. modules communicate via WMMN

The main component of the system is SAMIRA *mobile*. It is a case equipped with different sensors that is constantly installed on a locomotive and temporarily on the last wagon of a freight train as exemplarily shown in figure 4. It is the device that substitutes the worker standing on the last wagon and thus is responsible for monitoring the tracks and the environment and giving instructions to the driver. Therefore, SAMIRA *mobile* is equipped with a variety of sensors (figure 3) and an industrial computer that processes the gathered data. The long range

LiDAR and RADAR and the camera are responsible for obstacle and track detection. Appropriate algorithms and sensor fusion promise a small error rate. A global navigation satellite system (GNSS) receiver and an inertial measurement unit (IMU) allow the exact determination of the train's position which is needed for mapping purposes. Furthermore, a fish-eye camera is installed in order to monitor the close environment of the last wagon which is not in the field of vision of the sensors mentioned above. The used fish-eye camera has also a built-in system that obtains the odometry of the train. The mobile unit that is attached to the last wagon is equipped with a horn and a light for safety purposes.

Figure 4. SAMIRA *mobile* temporarily mounted on the last wagon monitoring the tracks and the environment. It communicates via WIFI respectively the WMMN. Here the system detects a brake-shoe.

While SAMIRA *mobile* is mounted on trains and moves, there exist steady units with sensors surveilling areas of high importance (e.g. railway crossings) or poor visibility from the train's viewpoint since it is covered by e.g. a building. These units are called SAMIRA *fixed* and are equipped with a LiDAR, a camera and a GNSS receiver in order to detect obstacles and determine its position for the global map as shown in figure 5. This map is generated by the edge server.

The last component is the HMI that is located inside the locomotive. On the one hand it enables the locomotive driver to adjust settings, change the direction of shunting (i.e. choosing which SAMIRA *mobile* is used—front or rear) and have an overview of the current system's state. On the other hand it displays the videostream that is generated inside the embedded computer of SAMIRA *mobile* with an overlayed augmented reality as depicted in figure 6. Detected obstacles are marked with bounding boxes in order to catch the driver's attention. The orange and green highlighting indicate the detected tracks and switch position while orange stands for

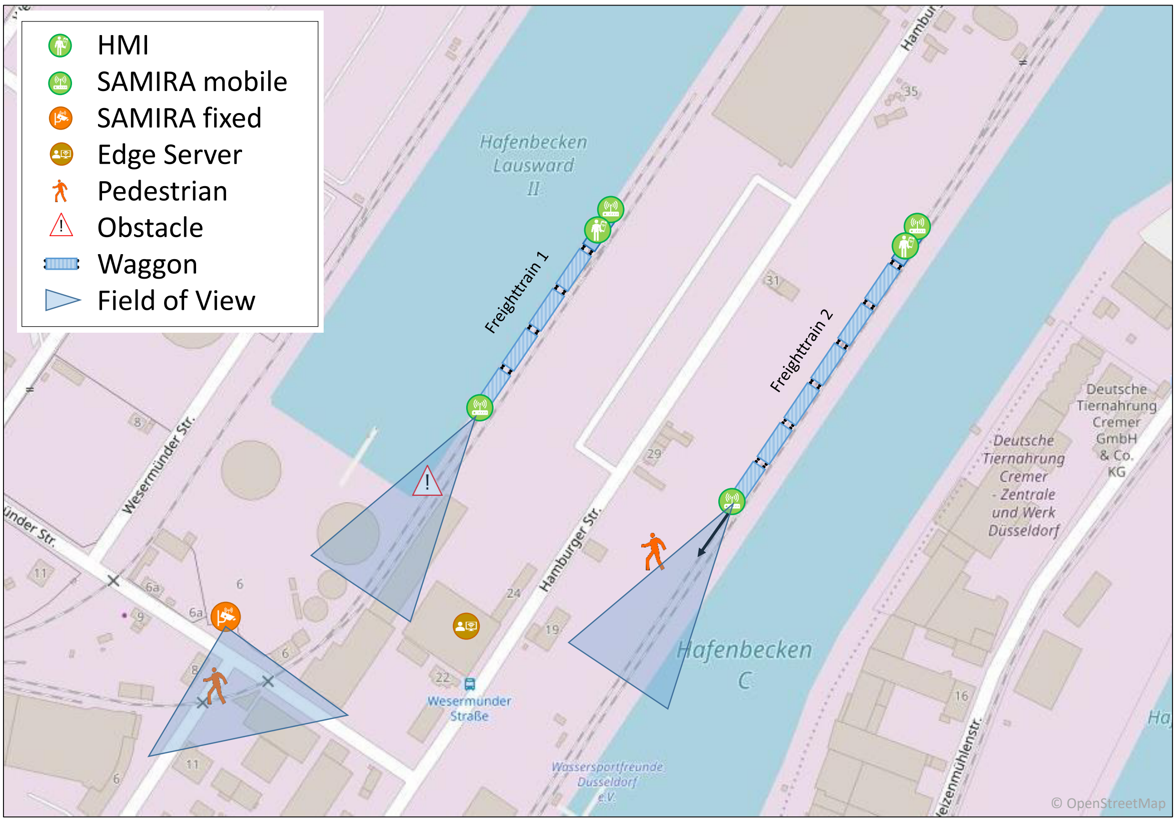

Figure 5. map showing all trains, monitoring devices and obstacles

the current braking distance and green for track vacancy. It helps the train driver assessing the situation and allows appropriate reactions. Furthermore, a map is displayed in order to show obstacles that are not yet to see in the videostream and give a global overview. In the bottom left corner there is a sign of life rotating indicating the system is working properly.

5 Application and economic benefits in sea port environment

It has been shown that both projects generate significant benefits in typical rail freight applications:

- Wagon 4.0: Saving of asset hours (locomotives, tracks) and staff hours by automatic condition monitoring and brake checking as well as using internal shunting motor instead of locomotives
- SAMIRA: Intelligent monitoring of movement spaces, tracks and environment

When applied together in sea port environments the benefits may even increase further. So intelligent freight wagons may be handled like autonomous container movers by the port au-

Figure 6. human machine interface displays augmented reality

tomation system removing inefficient manual interfaces and risky or heavy manual labour:

- Control of all vehicles can be centralized in port operations center
- Seamless integration of container handling and train movements
- Increase of workers safety as there is no need for manual labour on tracks anymore
- Heavy manual work is replaced by automation
- Remaining labour is more ergonomically designed and also suitable for aging workforce
- Faster train setup and brake check
- Less tracks needed as no locos need to put on other train side
- Higher speeds due to SAMIRA
- Higher capacity, throughput and efficiency of tracks and vehicles compared to legacy operations

The most important point is the higher troughput and efficiency. This applies to train turnaround times as well as track occupancy. Taking legacy operations (as already know from table 1) and the sample train shown in chapter 2, the new standard turnaround procedure will be as shown in table 2:

Table 2: New turnaround and handling times with SAMIRA and Wagon 4.0

Step	Description	Time legacy ops	Time new ops	sv. labour	sv. loco	sv. train	sv. track
1	Arrival and splitup	00:30	00:05	01:00	00:30	00:25	00:25
2	Unloading (4 stackers manual vs. autom.)	00:45	00:30	03:00	00:00	00:15	00:15
3	Inspection of train	00:30	00:00	00:45	00:00	00:30	00:30
4	Setting bolts and loading (4 stackers manual vs. autom.)	00:45	00:30	03:45	00:00	00:15	00:15
5	Assembly and brake check	01:30	00:10	02:00	01:20	01:20	01:20
Total		04:00	1:15				

So as easily can be seen, more than 66% of turnaround time may be saved and therefore rolling stock and track assets show significant better utilisation. Without changing track infrastructure, capacity of the facility increases by 200%. If we look into the cost savings and assume price of 1 Mio EUR for a wagon saving for each turnaround only on wagons will be 998 EUR. If we further take track occupancy also into account we will save additional 20%.

6 Conclusion

It has been demonstrated that combining Wagon 4.0 and SAMIRA result in many beneficial and money-saving effects. This was shown at the example of the port of Hamburg.

In this horbour, many small steps are currently necessary in freight traffic. Most of them are manually operated which is why the handling of the wagons takes a long time. The conventional train treatment takes about four hours without waiting times. This is just one reason, why a concept has been developed in order to automate and speed up those processes.

The main advantage that Wagon 4.0 provides is saving time—operating hours (locomotives, tracks) and staff hours—by automating the currently manually carried out operations with actuators. On the other hand, SAMIRA enables faster, safer and more comfortable shunting operations using different sensors in order to monitor the track. It is also a first approch in order to allow remote navigation from the inside of a control center in the future.

In sum: the fusion of both approaches constitutes a basis for autonomous driving in the railsector. Employees can be relieved from exhausting and dangerous work and operational safety can be increased. The presented solution enables faster train formation and brake testing as well as higher capacity, throughput and efficiency of tracks and vehicles compared to conventional methods which directly saves money and increases capacity.

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