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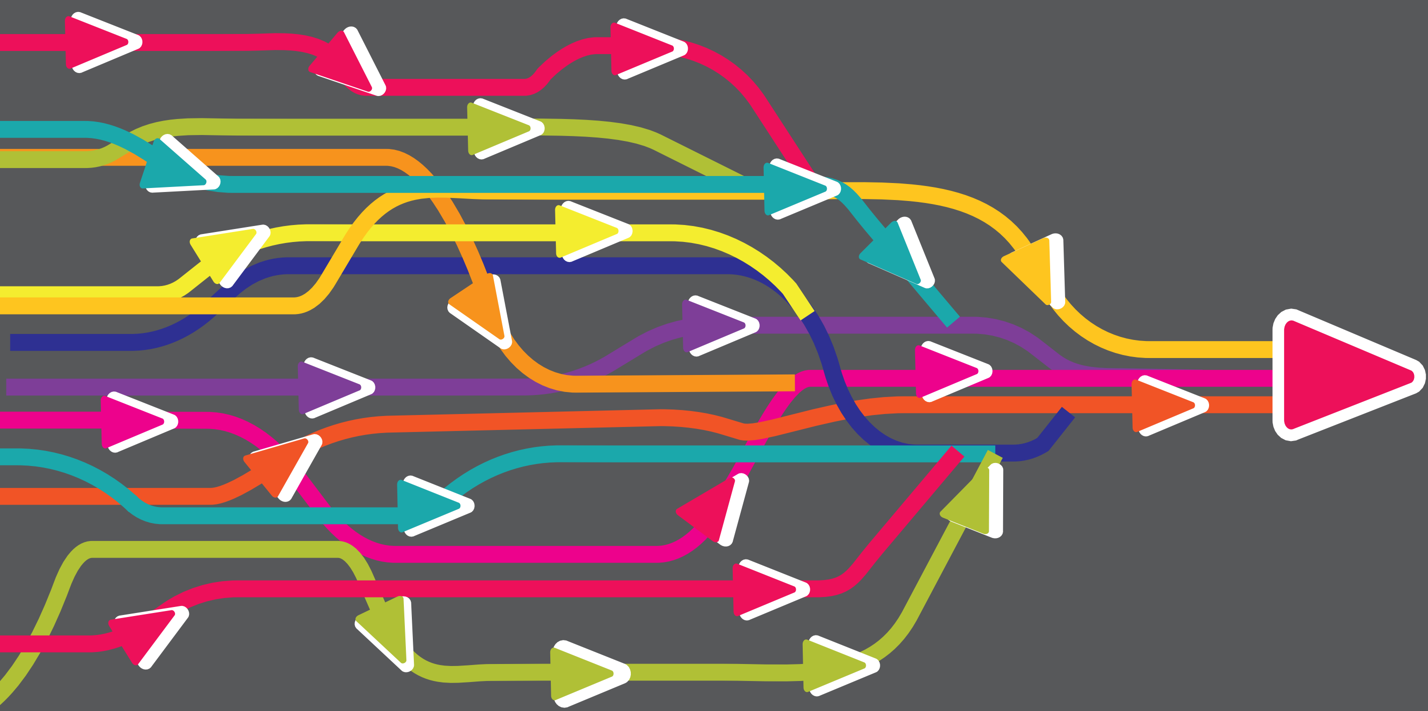

Technology Roadmapping

Part of Science Group

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Foreword

Our latest white paper explores TP Group's Technology Roadmapping expertise, presenting a case study of our techniques applied to a theoretical scenario. Our work in this area aligns strongly to our Concepts and Futures growth theme and is an area within which TP Group has particular pedigree and expertise having recently delivered these methods for Dstl and DE&S.

The ability to understand and plan for disruptive 'Generation After Next (GAN)' technological change is essential for any business, not least of which within the Defence arena where short term decisions can have far reaching impacts that might constrain your ability to operate in the future. Being cognizant of, and properly informed about, what the future technological landscape might be means you can plan better, not invest in 'dead end' or obsolete tech and pursue better, incremental improvements on a development spiral towards a greater whole – ultimately understanding the future disruption before it occurs.

I am thrilled to share this new thought leadership piece, and I hope you find our ideas as engaging and helpful as we do.

Dominic Černis

Chief Technical Officer

TPG Services Ltd.

Technology Roadmapping

Introduction

In order to fully exploit the technologies of the Generation After Next (GAN), it is vital that we are aware of what those technologies might offer as early as possible. In fact, a large number of those technologies already exist, ranging from concepts to prototypes, and the key decisions that need to be made relate to which ones need specific support, investment, or adaptation to be effective in a Futures Concept, as well as how they integrate with each other and a wider system.

This paper demonstrates a flexible technology roadmapping approach successfully used by TP Group, that uses a combination of open-source research and Subject Matter Expert (SME) opinions to give clients awareness of emerging technologies and visualise their expected development to support optimisation of operational effectiveness.

Hypothetical Scenario

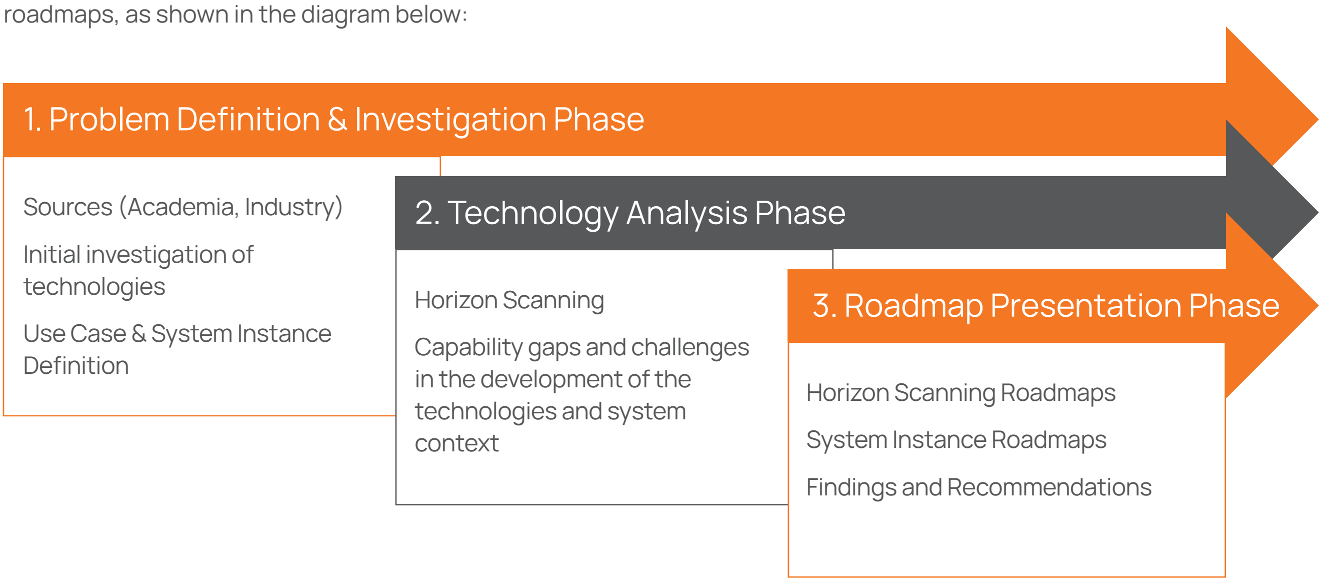
While intended for defence projects, for the purposes of presenting our roadmapping techniques in an unclassified and agnostic fashion, we have constructed a hypothetical scenario, described below:

A city is experiencing significant and regular congestion during peak usage times, caused in part by the inefficient use of cars, and the local council wants a solution. However, they are aware that cars are popular among residents, and any attempt to limit usage will be poorly received. It is suggested that autonomous vehicles may eventually be the solution to their problems, and now the council wants a study into how this may work.

We had access to an expert on autonomous vehicle technology and offered to support the council and run the study.

Overview of Approach

Our technology roadmapping approach is undertaken in three phases, starting by identifying possible solutions and investigating relevant technologies, leading into a deeper dive into said technologies, and culminating in a set of roadmaps, as shown in the diagram below:



These phases are detailed throughout this paper.

1. Problem Definition and Investigation Phase

The first phase of our study is to investigate the current state of the technology, and where it is heading, and to define a use case based on the problem. This phase mainly relates to gathering relevant information and planning for the rest of the phases.

Sources

First, our SME produced a list of every relevant source and supplier, from academics to corporations, who may be involved in current and future development of GAN autonomous cars, including secondary SMEs who were able to further expand the network. This enabled us to capture relevant information with a wide net, before downselection.

Technology Framework and Discovery Data

The source list was then analysed to extract all relevant technologies, and group them into relevant technology areas. This was done through both engagement with representatives of sources and reading publicly available materials.

Early in the process, it became apparent that autonomous vehicles could not be viewed in isolation, but also required infrastructural development in areas in which they will operate. This meant we chose to categorise by relevance to vehicles or infrastructure and discard all else. Additionally, we needed to remove any technologies that could be considered low level "building blocks", as we break down technologies further in the next phase. For example, battery technology could contribute to other technologies (e.g., electric cars), but cannot itself be easily broken down, so could be considered a building block. This produced a shortlist of technologies to analyse for both vehicular and infrastructural development.

These technologies were assessed using rough Technology Readiness Level (TRL) scores where:

- **TRL 1-3: Technologies that existed as a concept;**
- **TRL 4-6: Technologies that were developed and available as part of bespoke solutions;**
- **TRL 7-8: Technologies that existed as off-the-shelf solutions; and**
- **TRL 9: Technologies that were already deployed in the context we needed.**

We also noted any quantitative and qualitative data to support analysis, and any considerations of benefits and drawbacks of applying the specific technology.

Qualitative Technology Assessments

While we had an idea of the technologies at play, we also required an assessment of the potential in each technology to progress over time. Based on SME input, we used a qualitative scoring system to assess:

- **How much more effective will the technology be at TRL 9; and,**
- **How much will it cost to get this to TRL 9**

This scoring system compares the current state of the technology to our expectations of a GAN version of it. It scores on a scale from minor, suggesting iterative improvements and minor investment, to significant, suggesting paradigm shifting technology and major investment not only into the technology, but the surrounding ecosystem to support it.

Additionally, to better highlight where investment would need to be targeted, we asked:

- **Will this technology get to TRL 9 in GAN timescales without specific investment?**

These assessments were used to inform recommendations, as well as analysis in the next phase.

Use Case and System Instance Definition

With our newfound understanding of the technology space, we returned to the council's problem: how can GAN autonomous car technology solve the congestion problem?

This started by forming a use case based on the council's needs, defining the problems to solve, and requirements of the system. This formed the basis of producing our system instances. Using our shortlist, we produced a series of concepts, where combinations of technologies were used to create possible solutions. Some of these concepts were inspired by creation of a morphological matrix, by grouping mutually exclusive technologies, and generating all possible combinations. For example, we considered systems based on the type of autonomy (e.g., independent driverless cars, or centralised controller), and generated concepts with this as a category.

One system instance we created would be to use the city infrastructure to monitor traffic and provide centralised autonomous control for all cars in the area. The council were interested in exploring this idea further, so it was taken forward to the next phase.

2. Technology Analysis Phase

With both a technology shortlist, and a system instance to apply it to, we entered the technology analysis phase, where using a relevant SME and our data, we find the information needed to generate our roadmaps.

Horizon Scanning

To properly identify the possible development of the individual technologies, we assessed them along a set of Innovation Pathways, generic aspects of technology that contribute to a complete GAN version. The TRL definitions used in this stage were:

- **TRL 3: Technology existed in concept for the application;**
- **TRL 6: Technology was developed but not applied;**
- **TRL 8: Technology was operational;**
- **TRL 9: Technology had been applied in the field.**

In Table 1, we show an assessment breaking down a car into six key technologies that contribute to future development, and assess them individually, both in the present and across a series of epochs (typically 5-15 years) leading to the target GAN epoch.

Technology	Innovation Pathway	Required Technology	Current TRL	TRL at Epoch 1	TRL at Epoch 2	TRL at Epoch 3
Car	ICT	Self-driving technology	6	6	8	9
	Power Supply	Lithium-Ion Batteries	8	8	8	9
	Materials	Lightweight materials	6	8	8	9
	Manufacturing	Mass production	8	9	9	9
	Chemicals	Lithium Ions	3	6	6	9
	Human Interface	Brain Interface	3	3	6	8

Table 1: Horizon Scan for Car Technology

This process directly informs a set of roadmaps in the next phase, and gives an impression of what aspects of the technology are common across a variety of areas, including how much of a bottleneck that creates.

Additionally, the SME considered how technologies would fit into the wider system context, for example considering training, equipment, and legal needs for GAN cars to be used in the system.

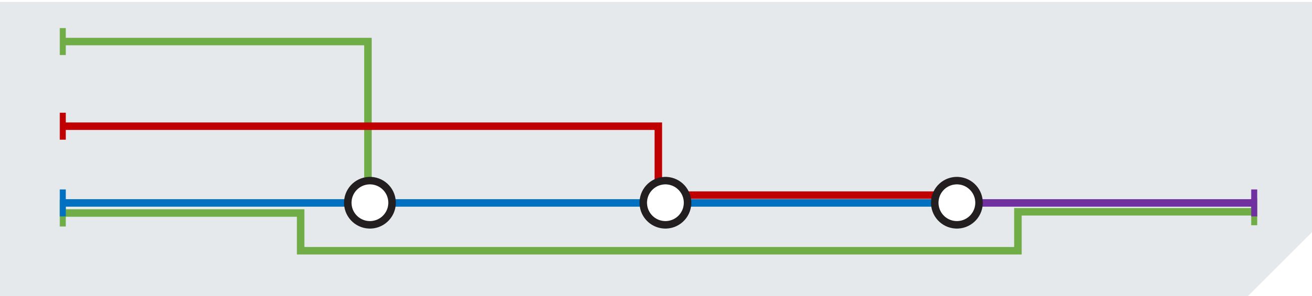
Using this data, we were able to move to the next phase, and produce our roadmaps.

3. Roadmap Presentation Phase

Tube Maps

Although it may be easier to present the council a spreadsheet with all the relevant facts and figures, most decision makers will appreciate a clear visual that displays all the pertinent information.

To this end, we based our roadmaps on the design language of the London Underground, with the lines representing the various technologies coming into 'stations', where some kind of meaningful change occurs, and leaving the 'stations' as new or changed lines.



Tab 1: Example Tube Map Structure

Horizon Scanning Roadmaps

In the Technology Analysis Phase, we considered technologies' development across individual innovation pathways. However, a key factor in technological progress is how new technologies can combine to create something new. In our Horizon Scanning roadmaps, we consider these combinations, with Figure 2 showing a roadmap based on Table 1.

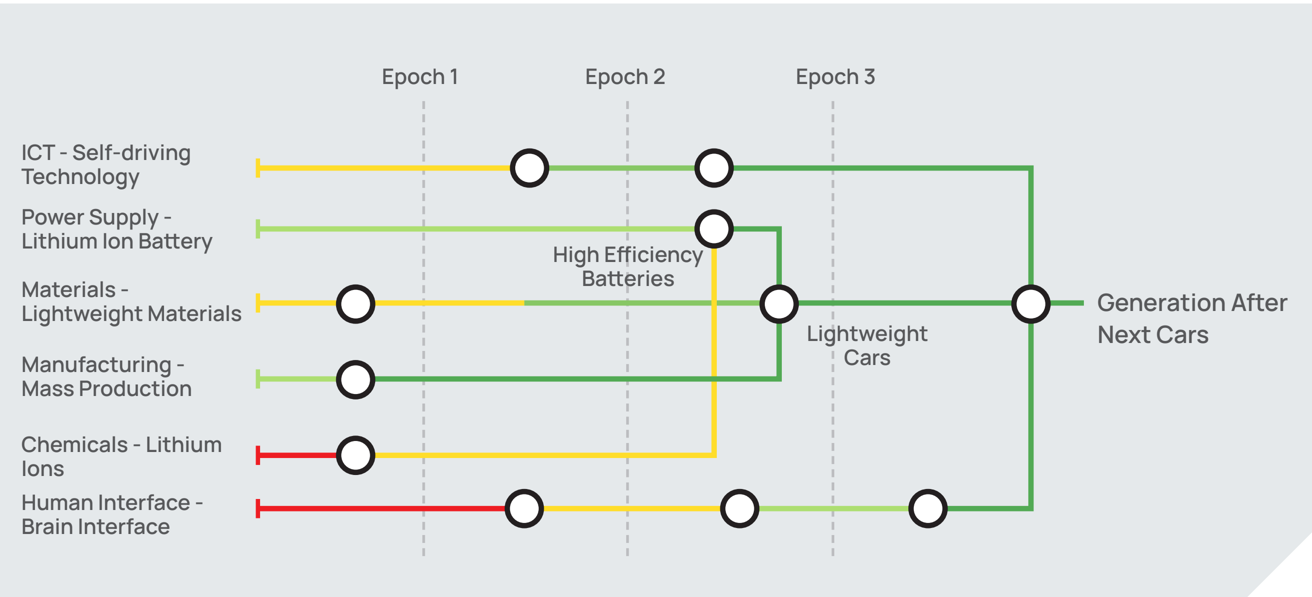


Figure 2: Example Horizon Scanning Roadmap for Car technology.

In the diagram above, it can be seen that we have used the same six innovation pathways, with the colour of the line representing the TRL score given above. While stations mark points where TRL changes within a pathway, they are also used to show where we could combine technologies to take advantage of progressing development. For example, the power supply and lithium-ion technologies are both related to battery development, and between Epoch 2 and 3, we expected them to converge into "High Efficiency Batteries", that can be assumed to develop as one. Additionally, as we do not expect the brain interface technology to be ready by Epoch 3, complete development of GAN Cars is shown to happen outside of the planned time period. This further informs our specific recommendations, for example suggesting that the brain interface cannot be included in the concept, otherwise there will likely be delays in producing the necessary car.

Similar roadmaps were generated for every downselected technology from the Investigation phase.

System Instance Roadmaps

Now that we better understand the technologies, and how they might develop and change, we can take a wider view, and see how they might fit into the wider system instance. Earlier in this paper, we created a system instance concept with a centrally monitored and controlled system for traffic management. This was split into technologies that relate to the cars, and those that relate to city infrastructure.

Once again using the tube map styling, we identified the building blocks of the system, and estimated how and when they might combine or develop into a part of the system, creating a concept of how existing ideas could become the proposed system.

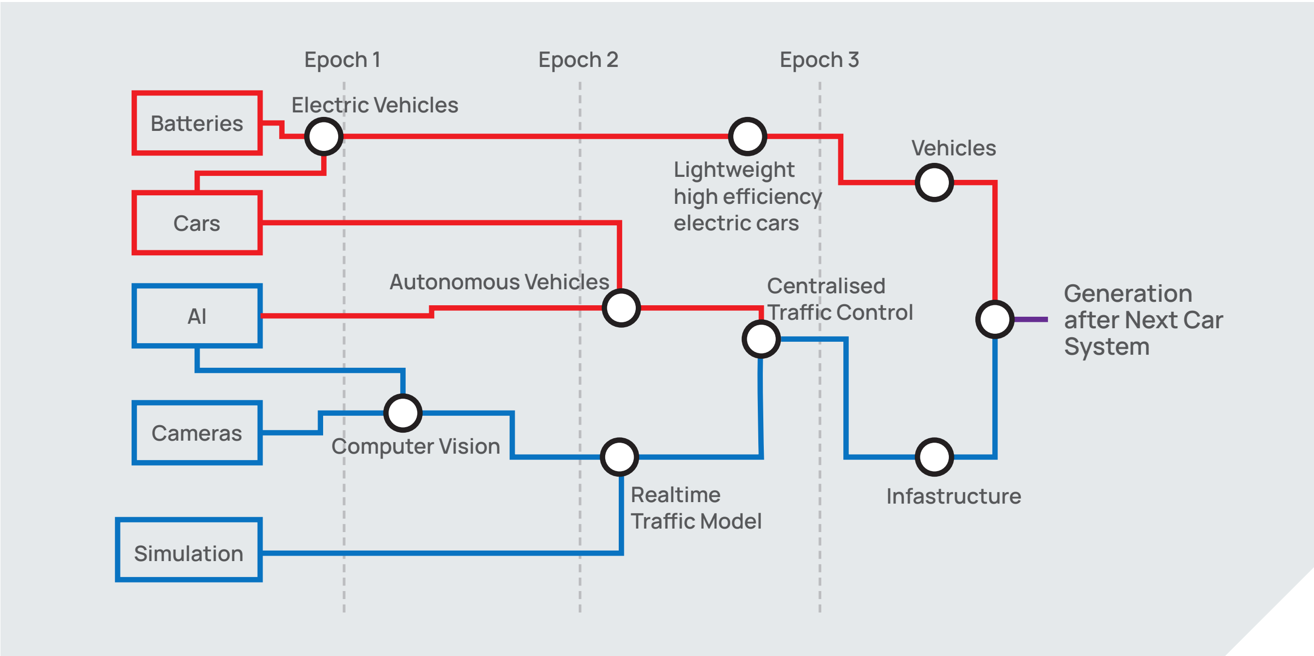


Figure 3: Example System Instance Roadmap

Findings and Recommendations

Throughout this process, we accrue significant amounts of data, and not all of this data can be effectively shown in a roadmap but should still be highlighted. For example, although market forces are likely to influence the development of vehicle related technologies, infrastructural changes are more complex. The council's preferred option, a centrally controlled model, may not be developed at all without targeted funding. Moreover, installation and implementation of the sensor and controller technologies will also require investment, otherwise the system will be inoperable.

Additionally, ill-timed investment can cause organisations to invest in a technological dead-end, which use of our roadmaps would mitigate. For example, if the council attempted to implement a Realtime Traffic Model before Epoch 2, when they come to integration into the full system, they may find that it lacks key features or performance developments required for the GAN Car System. They must therefore, either sacrifice the capability, or invest further into a replacement system. The roadmaps can also be used to highlight parallel development in multiple systems, that would allow early investment without commitment to any specific outcome. Roadmap analysis at this stage can highlight particular concerns and give stakeholders an impression of how to use the roadmaps to identify further findings.

Furthermore, this process generates many roadmaps (one horizon scanning roadmap per technology, and one roadmap per system instance), and this can be used to highlight obvious findings that may otherwise be overlooked, such the brain interface issue discussed earlier.

Conclusion

In this paper, we have been discussing how we might apply our technology roadmapping approach to a hypothetical non-defence scenario. However, while this approach was developed with defence in mind, the only significant change required to further generalise it was to remove specific defence related questions, for example how a technology may impact on Defence Lines of Development (DLoDs). We have otherwise demonstrated how this approach allows an analyst to assess and integrate technologies into a solution space.

TP Group has extensive experience of assessing relevant technologies, their applicability to defence use cases, and identifying optimal routes to integration within a system. We have used this approach on real-world defence projects, and in multiple disparate technology areas. For example, for expeditionary water infrastructure, we sought to identify possible means of extracting or generating water with minimal local impact, or human augmentation, where we roadmapped a set of medical telexistence systems to identify when technology would enable remote triage capabilities.

This demonstrates the versatility in our approach: with access to a relevant SME, we can form a detailed understanding of how any particular technology area can develop, and support stakeholders with a set of clear visuals and detailed analysis to assist them to make investment decision to achieve their objectives.

Acronyms

Acronym	Definition
DLoD	Defence Line of Development
GAN	Generation After Next
SME	Subject Matter Expert
TRL	Technology Readiness Level

About the Author – Jack Pottage

Jack is a Consultant specialising in Operational Analysis using data, modelling, visualisation and simulation. Jack has two years' of professional experience in OA, as well as a Master's degree in Engineering Mathematics. His recent work includes creating a user interface for generating model input data to use for CBRN hazard reduction, developing an approach to technology roadmapping and applying it to human augmentation, and designing a rules-based assessment to qualitatively assess future BLOS technologies in thousands of scenarios to support analysis of their potential use. He also provides assurance and support across a wider array of projects.

About TP Group

TP Group is a leading defence and security Consultancy, with a specific depth within Science and Technology. We draw upon our unique heritage to provide expert guidance and solutions, leveraging the insight from our experts to address specific client challenges. We work collaboratively across government and the defence industry to equip them to answer immediate, emerging and future challenges. We are relied upon to help navigate the landscape of accelerating next-generation technology, achieve greater efficiency across their operations, and to solve their most pressing issues.

Find out more about our expertise and experience within the defence sector at

tpgroupglobal.com/markets-we-serve/defence

If you are interested in discussing a project with us please email us **enquiries@tpgroup.uk.com**

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