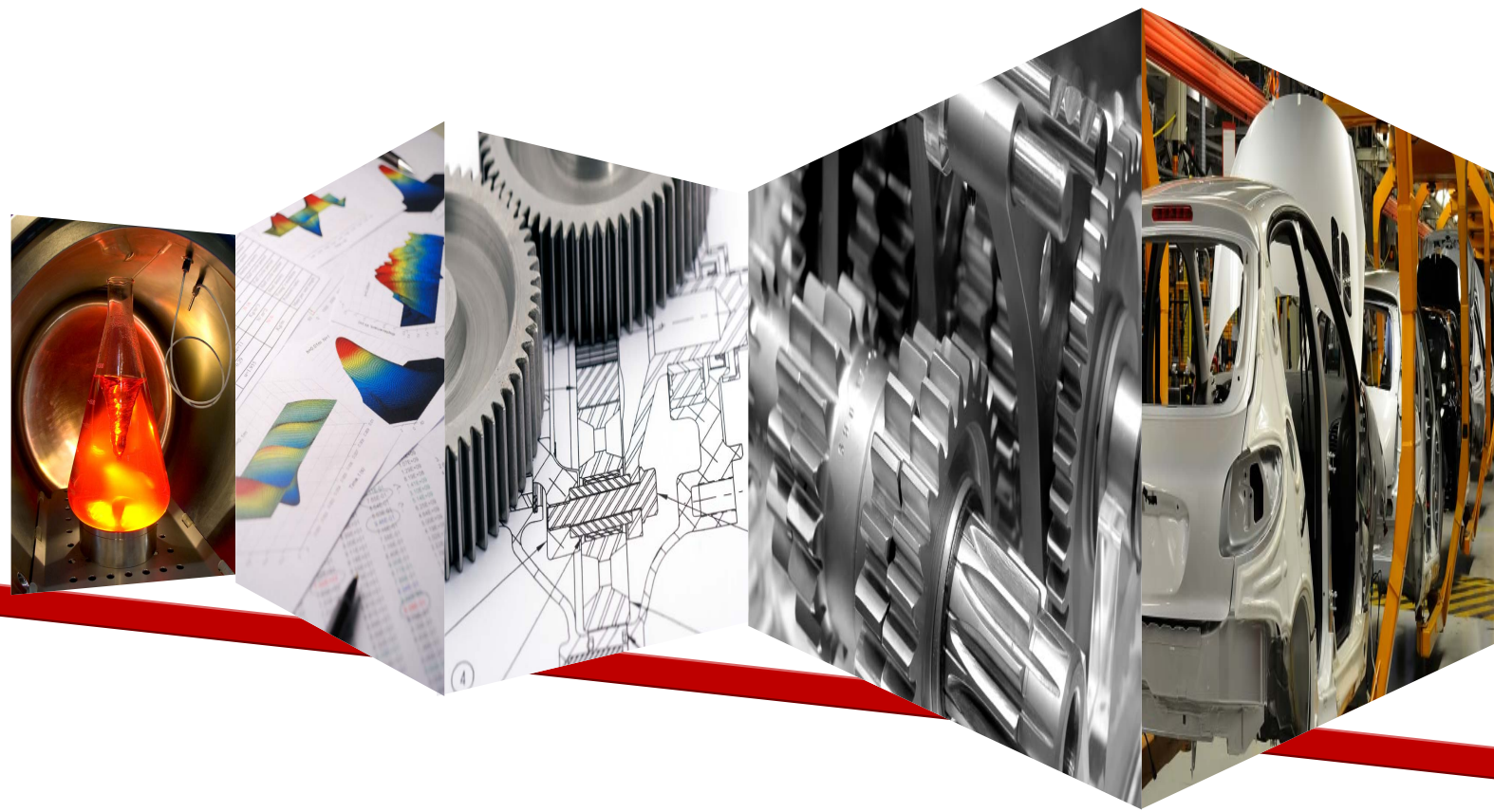


Automotive Technology and Manufacturing Readiness Levels

*A guide to recognised stages of development
within the Automotive Industry*



Foreword



Good, clear communication firms the ground for exploring new ventures, common areas of interest and establishing new relationships. Within engineering sectors, communication is paramount to achieving high quality products and using resources most efficiently and effectively.

There is an ongoing need for greater cooperation, joint exploration of new designs and acquisition of evolutionary and revolutionary products in order to rebuild the strengths of the UK's Automotive Sector. This set of 'readiness' levels assists the sector by providing specific, identifiable stages of maturity, from early stages of research through to supply chain entry.

I hope you will join others in implementing this framework for technology development, using it as a basis for further planning and communication, and gaining further benefit from its use.

Professor Richard Parry-Jones CBE
Co-Chairman of the Automotive Council

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Introduction to Technology and Manufacturing Readiness Levels (TRLs and MRLs)

A recurring issue to developers and adopters of new technologies is how to successfully communicate their accomplished or expected stages of technology development and readiness for manufacture. This set of Automotive TRLs and MRLs aims to help facilitate this dialogue and in doing so help with technology commercialisation, development work with new partners, planning supplier engagement and bringing new capabilities to market, through common understanding. Readiness levels provide common terms to define technology from concept to commercial production and through to disposal, and have a proven effectiveness from the aerospace and defence sectors. Independently, readiness levels can also assist with self-assessment, monitoring progress and planning goals and actions.

Benefits

- Emergent supply chain companies have a framework through which they can better understand the engagement needs of Tier1s/VMs.
- VMs, Tier1s and funding agencies are presented with clear definitions for present and targeting levels of development status.
- A framework can be used to provide clearer direction regarding engagement of the most appropriate public sector support.
- Angels/VC investor interest can be strategically aligned to product requirements.
- Self assessment provides guidance on next steps (trials, certification etc) relevant to Level and signposts sources of support.
- Sector-wide assessments and initiatives have a common framework to build upon.

These are a few of the benefits that are realised through common understanding.

Application to Integrated Assemblies and Roadmaps

When components are brought together and integrated, their individual TRL and MRL contribute to the readiness of the overall assembly. Integrated systems may contain components with different levels of readiness, influencing the status of the assembly overall. The use of readiness levels in such cases can highlight areas for focus and prioritisation in order to make best progress.

When considered with a timeframe in mind, readiness levels help depict the development path or time to implement next generation technologies or derivatives with respect to established products, similar to technology roadmaps and highlighting strengths and weaknesses in proposed or emerging systems.

Readiness levels also offer the ability to assess complete systems at a high level, the electrification of transport for example, and to focus in on contributing components, such as battery technologies or infrastructure integration.

Relationship between Technology Readiness and Manufacturing Readiness Level

The table which follows details ten stages of maturity for a product to:

- deliver its function (Technology Readiness)
- be produced (Manufacturing Readiness)

These levels are staggered in the table since advancing technological capability logically progresses ahead of manufacture. For each Technology Readiness Level the corresponding Manufacturing Readiness Level is that which is usual. It should be noted however that some technologies can deviate from these levels.

Automotive Technology and Manufacturing Readiness Levels

| TRL | Technology Readiness | MRL | Manufacturing Readiness |
|-----|--|-----|---|
| 1 | <ul style="list-style-type: none"> • Basic Principles have been observed and reported. • Scientific research undertaken. • Scientific research is beginning to be translated into applied research and development. • Paper studies and scientific experiments have taken place. • Performance has been predicted. | | |
| 2 | <ul style="list-style-type: none"> • Speculative applications have been identified. • Exploration into key principles is ongoing. • Application specific simulations or experiments have been undertaken. • Performance predictions have been refined. | | <ul style="list-style-type: none"> • A high level assessment of manufacturing opportunities has been made. |
| 3 | <ul style="list-style-type: none"> • Analytical and experimental assessments have identified critical functionality and/or characteristics. • Analytical and laboratory studies have physically validated predictions of separate elements of the technology or components that are not yet integrated or representative. • Performance investigation using analytical experimentation and/or simulations is underway. | 1 | <ul style="list-style-type: none"> • Basic Manufacturing Implications have been identified. • Materials for manufacturing have been characterised and assessed. |
| 4 | <ul style="list-style-type: none"> • The technology component and/or basic subsystem have been validated in the laboratory or test house environment. • The basic concept has been observed in other industry sectors (e.g. Space, Aerospace). • Requirements and interactions with relevant vehicle systems have been determined. | 2 | <ul style="list-style-type: none"> • Manufacturing concepts and feasibility have been determined and processes have been identified. • Producibility assessments are underway and include advanced design for manufacturing considerations. |
| 5 | <ul style="list-style-type: none"> • The technology component and/or basic subsystem have been validated in relevant environment, potentially through a mule or adapted current production vehicle. • Basic technological components are integrated with reasonably realistic supporting elements so that the technology can be tested with equipment that can simulate and validate all system specifications within a laboratory, test house or test track setting with integrated components • Design rules have been established. • Performance results demonstrate the viability of the technology and confidence to select it for new vehicle programme consideration. | 3 | <ul style="list-style-type: none"> • A manufacturing proof-of-concept has been developed • Analytical or laboratory experiments validate paper studies. • Experimental hardware or processes have been created, but are not yet integrated or representative. • Materials and/or processes have been characterised for manufacturability and availability. • Initial manufacturing cost projections have been made. • Supply chain requirements have been determined. |

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| 6 | <ul style="list-style-type: none"> • A model or prototype of the technology system or subsystem has been demonstrated as part of a vehicle that can simulate and validate all system specifications within a test house, test track or similar operational environment. • Performance results validate the technology's viability for a specific vehicle class. | 4 | <ul style="list-style-type: none"> • Capability exists to produce the technology in a laboratory or prototype environment. • Series production requirements, such as in manufacturing technology development, have been identified. • Processes to ensure manufacturability, producibility and quality are in place and are sufficient to produce demonstrators. • Manufacturing risks have been identified for prototype build. • Cost drivers have been confirmed. • Design concepts have been optimised for production. • APQP processes have been scoped and are initiated. |
| 7 | <ul style="list-style-type: none"> • Multiple prototypes have been demonstrated in an operational, on-vehicle environment. • The technology performs as required. • Limit testing and ultimate performance characteristics are now determined. • The technology is suitable to be incorporated into specific vehicle platform development programmes. | 5 | <ul style="list-style-type: none"> • Capability exists to produce prototype components in a production relevant environment. • Critical technologies and components have been identified. • Prototype materials, tooling and test equipment, as well as personnel skills have been demonstrated with components in a production relevant environment. • FMEA and DFMA have been initiated. |
| 8 | <ul style="list-style-type: none"> • Test and demonstration phases have been completed to customer's satisfaction. • The technology has been proven to work in its final form and under expected conditions. • Performance has been validated, and confirmed. | 6 | <ul style="list-style-type: none"> • Capability exists to produce integrated system or subsystem in a production relevant environment. • The majority of manufacturing processes have been defined and characterised. • Preliminary design of critical components has been completed. • Prototype materials, tooling and test equipment, as well as personnel skills have been demonstrated on subsystems/ systems in a production relevant environment. • Detailed cost analyses include design trades. • Cost targets are allocated and approved as viable. • Producibility considerations are shaping system development plans. • Long lead and key supply chain elements have been identified. |
| 9 | <ul style="list-style-type: none"> • The actual technology system has been qualified through operational experience. • The technology has been applied in its final form and under real-world conditions. • Real-world performance of the technology is a success. • The vehicle or product has been launched into the market place. • Scaled up/down technology is in development for other classes of vehicle. | 7 | <ul style="list-style-type: none"> • Capability exists to produce systems, subsystems or components in a production representative environment. • Material specifications are approved. • Materials are available to meet planned pilot line build schedule. • Pilot line capability has been demonstrated including run at rate capability. • Unit cost reduction efforts are underway. • Supply chain and supplier Quality Assurances have been assessed. • Long lead procurement plans are in place. • Production tooling and test equipment design & development has been initiated • FMEA and DFMA have been completed. |

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| | | 8 | <ul style="list-style-type: none"> • Initial production is underway • Manufacturing and quality processes and procedures have been proven in production environment. • An early supply chain is established and stable. • Manufacturing processes have been validated. |
| | | 9 | <ul style="list-style-type: none"> • Full/volume rate production capability has been demonstrated. • Major system design features are stable and proven in test and evaluation. • Materials are available to meet planned rate production schedules. • Manufacturing processes and procedures are established and controlled to three-sigma or some other appropriate quality level to meet design characteristic tolerances in a low rate production environment. • Manufacturing control processes are validated. • Actual cost model has been developed for full rate production. |
| 10 | <ul style="list-style-type: none"> • The technology is successfully in service in multiple application forms, vehicle platforms and geographic regions. In-service and life-time warranty data is available, confirming actual market life, time performance and reliability | 10 | <ul style="list-style-type: none"> • Full Rate Production is demonstrated • Lean production practices are in place and continuous process improvements are on-going. • Engineering/design changes are limited to quality and cost improvements. • System, components or other items are in rate production and meet all engineering, performance, quality and reliability requirements. • All materials, manufacturing processes and procedures, inspection and test equipment are in production and controlled to six-sigma or some other appropriate quality level. • Unit costs are at target levels and are applicable to multiple markets. • The manufacturing capability is globally deployable. |

Examples

Below are two examples of levels applied to automotive technologies.

Composite Structures for mass market automotive applications

| TRL | Technology Readiness | MRL | Manufacturing Readiness |
|----------|--|----------|--|
| 8 | <ul style="list-style-type: none"> • Test and demonstration phases have been completed to customer's satisfaction. • The technology has been proven to work in its final form and under expected conditions. • Performance has been validated, and confirmed. | 4 | <ul style="list-style-type: none"> • Capability exists to produce the technology in a laboratory or prototype environment. • Series production requirements, such as in manufacturing technology development, have been identified. • Processes to ensure manufacturability, producibility and quality are in place and are sufficient to produce demonstrators. • Manufacturing risks have been identified for prototype build. • Cost drivers have been confirmed. • Design concepts have been optimised for production. • APQP processes have been scoped and are initiated. |

ABS for multiple vehicle class, automotive applications

| TRL | Technology Readiness | MRL | Manufacturing Readiness |
|-----------|---|-----------|---|
| 10 | <ul style="list-style-type: none"> • The technology is successfully in service in multiple application forms, vehicle platforms and geographic regions. In-service and life-time warranty data is available, confirming actual market life, time performance and reliability | 10 | <ul style="list-style-type: none"> • Full Rate Production is demonstrated • Lean production practices are in place and continuous process improvements are on-going. • Engineering/design changes are limited to quality and cost improvements. • System, components or other items are in rate production and meet all engineering, performance, quality and reliability requirements. • All materials, manufacturing processes and procedures, inspection and test equipment are in production and controlled to six-sigma or some other appropriate quality level. • Unit costs are at target levels and are applicable to multiple markets. • The manufacturing capability is globally deployable. |