TM Forum Introductory Guide

Guiding Principles for building and measuring Autonomous Network Solutions

IG1229

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Notice

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Terminology

Term	Definition / Source
Autonomy	The capability to make decisions free from human control.
Accountability	Accountability requires the AI and people behind the AI explain, justify, and take responsibility for any decision and action made by the AI. Mechanisms, such as governance and tools, are necessary to achieve accountability.
Responsibility	
Observability	
Explainability	Explainability is the ability to explain how AI works (i.e. make their decisions). Explanations should be produced regarding both the procedures followed by the AI (i.e., its inputs, methods, models, and outputs) and the specific decisions that are made. These explanations should be accessible to people with varying degrees of expertise and capabilities including the public. AI engineering discipline should be sufficiently advanced such that technical experts possess an appropriate understanding of the technology, development processes, and operational methods of its AI systems, including the ability to explain the sources and triggers for decisions through transparent, traceable processes and auditable methodologies, data sources, and design procedure and documentation. [1]
SON	Self-Organizing Network

[1] Derived from ACM Principles for Algorithmic Transparency and Accountability https://www.acm.org/binaries/content/assets/publicpolicy/2017_usacm_statement_algorithms.pdf

1 Purpose

This document outlines a set of guiding principles to help support design, build, and measurement of an autonomous network (AN) solution. The principles are varied: some are high level to guide solutions design, whereas others address more granular issues regarding contextual, cultural, and pragmatic aspects of an implementation.

The document is intended as a complement to the AN business architecture[ref 10] and technical reference architecture [ref 11]. The AN business architecture takes a top-down customer-oriented approach, whereas this document considers the broader set of business and operational drivers that will need to be considered when adopting an AN. The AN technical architecture provides a technical reference architecture on which to base a solution design, whereas this document focuses on some of the pragmatic operational aspects of a solution. Both the business architecture and technical reference architecture cover the AN levels of autonomy, whilst this document outlines observability requirements for an AN solution more broadly.

2 Target Audience

The target audience for this document is

- enterprise architects and technology planners involved in planning todays and tomorrows network solutions
- product managers of service, network, and operational support products sold into telco and enterprise markets
- software developers and solution integrators involved in implementing network solutions and automation initiatives
- operations specialists involved in running todays customer-facing and resource-facing operations teams

3 Introduction

The words "autonomous network" (or indeed "autonomous <anything>!") prompts many questions!

- How will they work?
- What will they cost?
- Will humans be needed at all in the future!?
- If there are few (or no) humans involved what happens when the Autonomous Network (or AN for short) degrade and/or fail?
- How will the AN know when it is failed?
- How do we know that the AN will be fair and equitable to all customers, partners, and users?

No one has definitive and detailed answers for all these [and many other] practical questions. What is clear, however, is that networks with level 5 autonomy are still quite a long way off. Until they exist the AN consists of teams of humans and machines collaborating to deliver and sustain services. This collaboration is very important to secure successful business outcomes and is discussed later in this document.

Telecom is not the first sector to embrace autonomy, and so it is possible to learn and infer from experiences in other sectors, such as manufacturing, automotive, and shipping (see references 1-5). Research into these learnings has resulted in a set of categories of relevant guiding principles for AN, summarized by category in Appendix I, which are explored in the rest of this document.

Figure 1 Guiding Principles (Categorized)

The following chapters will describe the principles belonging to the categories. The numbers in the Figure 2 AN Guiding Principles corresponds to the section it is covered in.

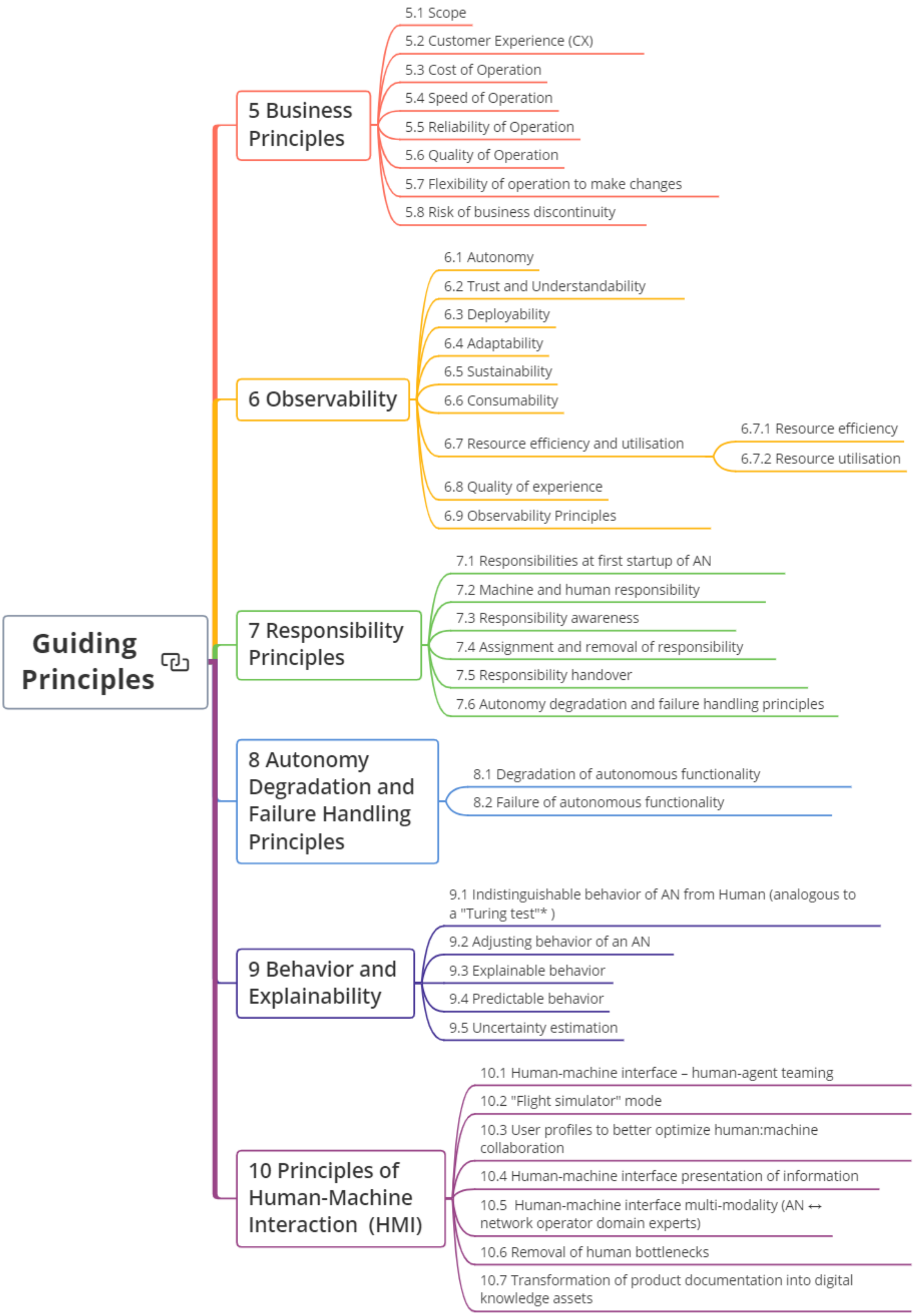

Figure 2 AN Guiding Principles

4 Business Drivers

The drivers for AN will vary from CSP to CSP, but fundamentally they are not so different to the drivers of any type of commercial production operation. A CSP is also a production operation, producing connectivity and connectivity related services. Using general economic theory 4 factors of production as a basis the factors of production are depicted in Figure 3.

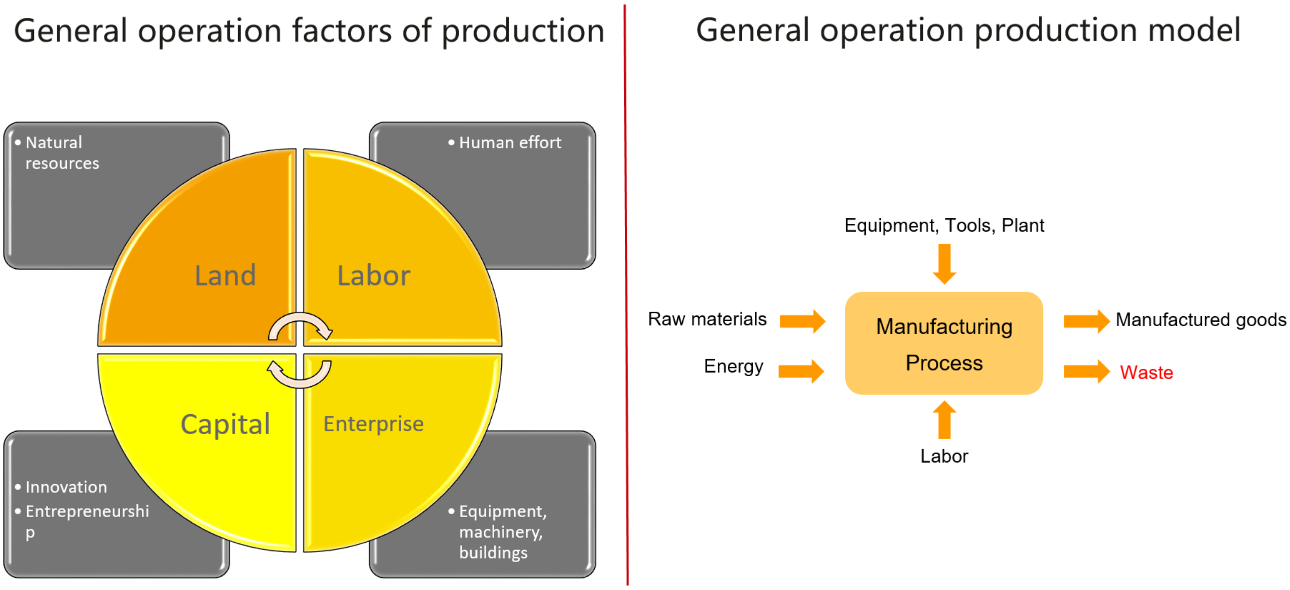

Figure 3 General economic theory: factors of production, and production model

Production processes generally make use of capital and labor to convert raw materials into finished products, and inevitably there is some amount of waste which impacts profitability.

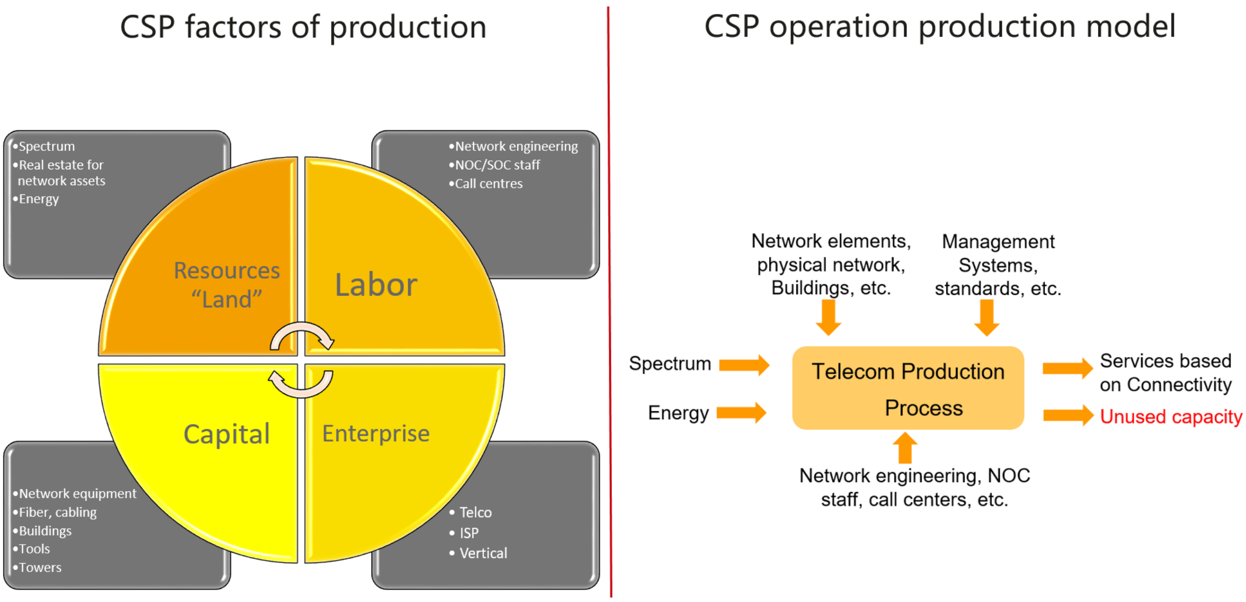

Figure 4 CSP Factors of production, production model

Applying the same logic to the CSP: the production process converts energy into ICT services, using network and IT infrastructure and the people who operate them, as depicted in Figure 4. If all of the engineered network capacity is not used, then there is also waste. These simplified production models essentially set out the main levers that an organization has to change business outcomes. They can expand their channels to market via various ecosystems, which should reduce unused capacity, but this requires the production model to transform. Many companies in manufacturing industries have already transformed by adopting technologies (e.g. industrial robots) and created highly automated flexible manufacturing engines. ANs can transform the CSP production model in the same way, increasing resource utilization and energy efficiency, and creating network services tailored to customer needs.

Although all operations processes are similar in that they all transform inputs, they do differ in a number of ways, four of which, known as "the four Vs" according to ref[6], are particularly important:

● the **volume** of their output

● the **variety** of their output

● the **variation** in the demand for their output

● the degree of **visibility** which customers have of the creation of their output.

All four dimensions have implications for the cost of creating and delivering services and products. Put simply: high volume, low variety, low variation, and low customer contact all help to keep processing costs down. Conversely, low volume, high variety, high variation, and high customer contact will generally carry a cost penalty for the operation. This is best illustrated with the "operations typology" chart used in ref [6], as depicted in Figure 5.

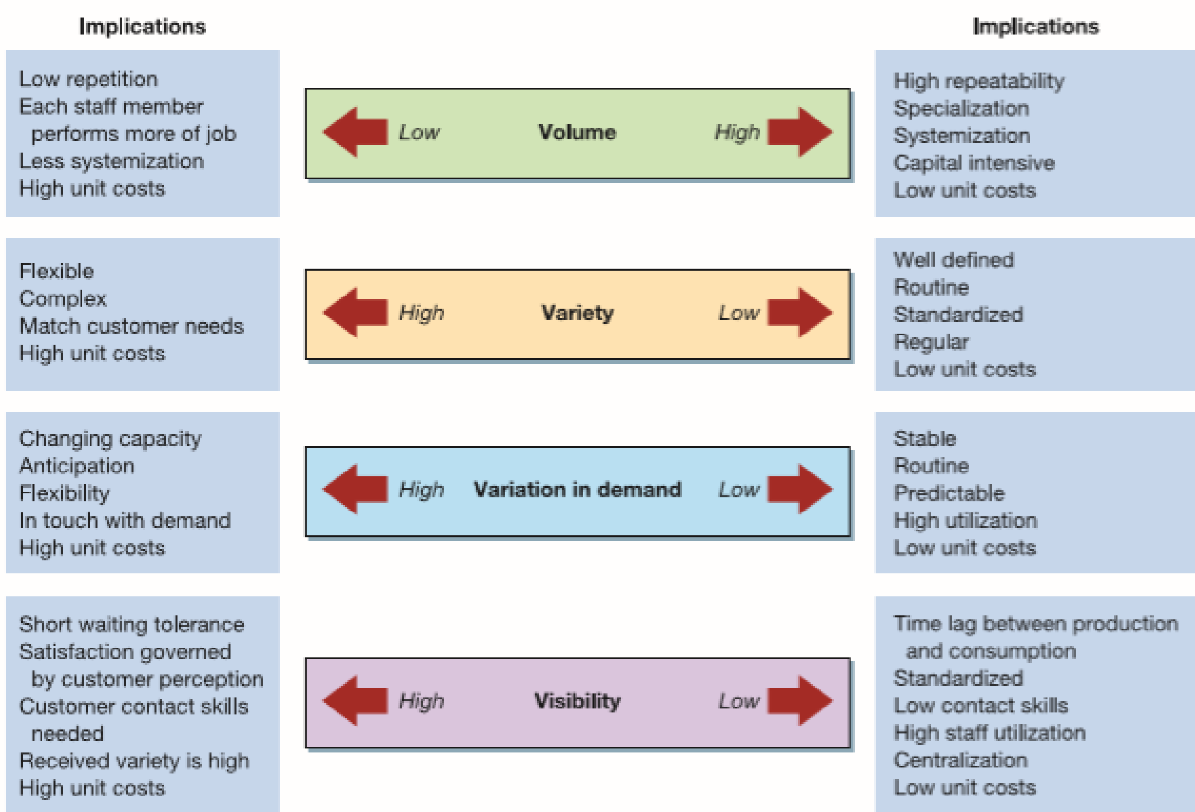

Figure 5 Operations typology - the 4 Vs

Different CSPs will have varying ambitions on each of these "V"s according to their business strategy, all with their own trade-offs. The AN must allow a CSP achieve the appropriate level of "V" for each market segment, or even partner or customer (if required). Analyzing any of the main public cloud service providers through these "V" prisms its evident they have designed their platform and products to:

- be very high volume if required, and, critically, without a corresponding increase in cost
- provide a reasonable (but not infinite) amount of variety
- provide great ability to handle variations in demand (scale up, scale down)
- provide acceptable visibility through the use of APIs and intelligent agents(bots)

These are good baseline targets for a CSP also.

An operation contributes to business strategy by achieving the following performance objectives:

1. Doing things right, resulting in a **quality** advantage
2. Doing things fast, resulting in a **speed** advantage
3. Doing things on time, resulting in a **reliability** (or dependability) advantage
4. Changing the things that are done, resulting in a **flexibility** advantage
5. Doing things cheaply, resulting in a **cost** advantage
6. Focusing on the customer, resulting in **reputation and brand** advantages that enable pricing power versus the competition
7. Keep doing things in times of adversity, resulting in a **business continuity** advantage

The commercial success of AN should be judged using all of these objectives, and thus they should underpin the principles used when designing and implementing an AN solution.

5 Business Driver Principles

Every CSP is different, and so are their precise business drivers. Thus principles 1-7 below will apply in different amounts to each customer. As described in ref [10] and ref[11] these are expressed with intent, at customer, partner, business, and service and network operational layers, and the role of the AN will be to reconcile and resolve the conflicts, both initially and on an ongoing basis.

5.1 Scope

Everything within the AN shall not need to be fully (or even partially) autonomous, it may not be justified from a business perspective. This is an overarching principle to remind us that its extremely unlikely (or even infeasible) that every single part of the CSP business will be fully autonomous. In fact, in some cases, too much autonomous behavior may be counterproductive, and create more issues than it resolves. Per ref[7] the performance of the human-machine system increases with the autonomy of the machine, but only until some optimum, after which it decreases. That is because if the autonomy of the machine is further increased, the human operator is likely to lose control of the situation, and performance then regresses, as shown in Figure 6 below.

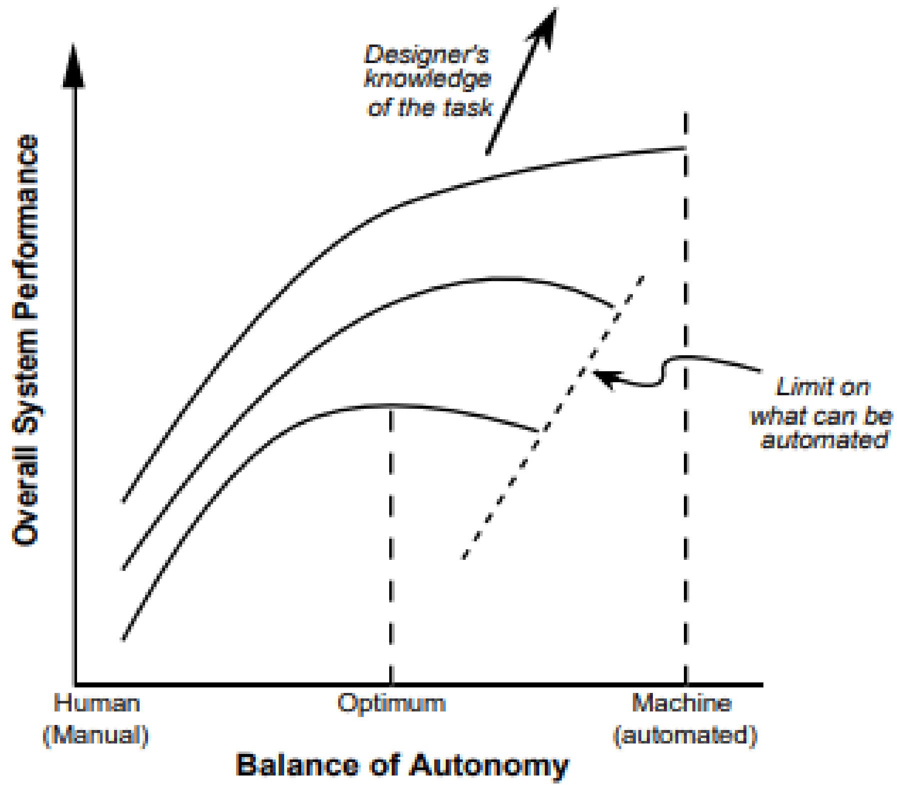

Figure 6 Balance of Autonomy

Furthermore, excessive automation tends to lower the level of vigilance of human operators of highly automated systems, that is: the more intelligent a system is the more complacent the human operator becomes - this can also be counterproductive. Thus: not every function should reach L5 autonomy.

This could be revisited when industry efforts have realized systems that are getting close to L5 autonomy, this is not in the near term, however.

5.2 Customer Experience (CX)

Customer experience shall, for most CSPs, be a key driving factor when considering and deciding how autonomous a function or domain should be. The focus shall be on how customer is going to experience the product (or service) provided by the network and what happens if and when it fails or degrades.

5.3 Cost of Operation

Cost of sustainment (or cost to operate) shall drive the need to implement autonomous behavior. Generally, functions that are more costly and onerous to operate should be prioritized over ones that are less costly. The AN shall help the CSP deliver products and services at lower per unit costs, maximize the utilization of their assets, and minimize waste.

5.4 Speed of Operation

Speed of operation shall drive the need to implement autonomous behavior. Functions that are slow, or that regularly become bottlenecks, are obvious candidates to target for some (or full) autonomy. The AN shall help the CSP reduce execution times across all tasks and disciplines: service design and creation, network rollout, service, network, and customer provisioning, assurance, billing, rating, migrations, service retirement, etc.

5.5 Reliability of Operation

Reliability (or dependability) shall drive the need to implement autonomous behavior. Reliability means doing things in time so that customers receive the right set of products and services exactly when they are needed, or at least when they were promised. Over the long term being reliable translates into time and cost savings, improving the business reputation, and ultimately increasing future revenue potential. The AN shall help the CSP become more reliable.

5.6 Quality of Operation

Quality is consistent conformance to customers (and partners and regulators) expectations - in other words "doing things right". "Doing things right" shall drive the need for autonomous behavior. In some way's quality is the most visible part of what a CSP does from a customer perspective, and thus is related to guiding principle #1 because its often perceived(especially bad experience), but quality is about more than customer experience. The AN shall help the CSP deliver error-free products and services which are ‘fit for purpose’.

5.7 Flexibility of operation to make changes

Flexibility of operation shall drive the need to implement autonomous behavior.

Today customers demand greater flexibility in the following ways:

- product/service flexibility – ability to introduce new or modified products and services
- product/service mix flexibility – ability to produce a wide range or mix of products and services
- volume flexibility – ability to change level of output or activity to support different product volumes, or capacities
- delivery flexibility – ability to change the timing of delivery of services and products.

The AN shall help the CSP become more flexible to customers changing needs.

5.8 Risk of Business Discontinuity

Risk of business discontinuity shall drive the need to implement autonomous behavior. Business discontinuity can happen for several reasons; examples would be IT security attacks, or organizational competence gaps (e.g. due to CSP staff aging demography, or faster pace of technological change). The AN shall enable the CSP to have more robust business continuity plans and procedures.

6 Observability

To see what is going on inside a system under observation, the system must be observable. That is: there must be measures, or metrics, produced by the system that can be monitored externally.

Autonomy will be the metric used to translate to the autonomous levels mentioned in the business architecture[ref 10] and technical ref architecture[ref 11]. If, for example, a network domains autonomy is 100% (i.e. all activities are performed by a machine and no activities are performed by humans) then this would translate to autonomous level 5. While the autonomous level is informative about the system capability in terms of autonomous behavior it is not the only measure needed to ensure a successful business outcome when using an AN.

In general, as a system gets more autonomous more (not less) observability data is needed to assure that everything is working correctly, and to better effect than traditional more manual methods.

3GPP observability focus has been on specific network performance indicators which, in most cases, were observed by humans. As autonomy levels increase machines will do more of these observations, and take more decisions that, ordinarily, are taken by humans today. Thus: these automated processes and the logic that drives them need to be more observable. A candidate set of observability categories are outlined below. Note that these are not fully elaborated metrics and formulae.

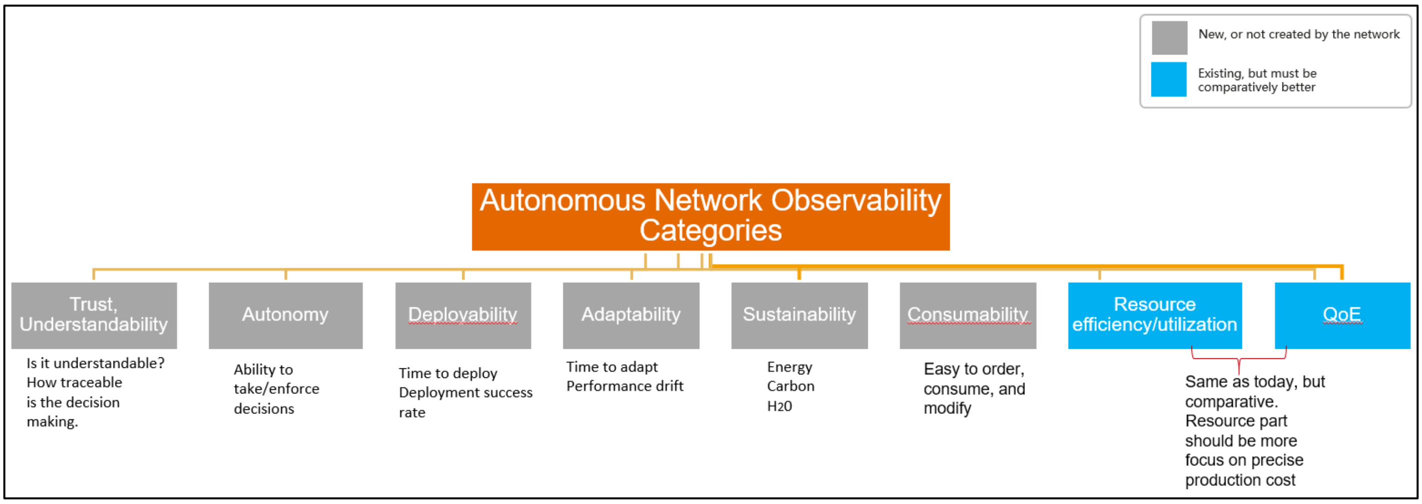

Figure 7 Observability

6.1 Autonomy

The autonomy of a system is measure of its ability to make choices and enforce its decisions. To have autonomy (or act autonomously) the system must have (1) intelligence and (2) capability, and these are both bounded, as shown in Figure 8. There is little or no value in building an extremely intelligent system that can make many choices independently if the system does not have the capability to implement the choices.

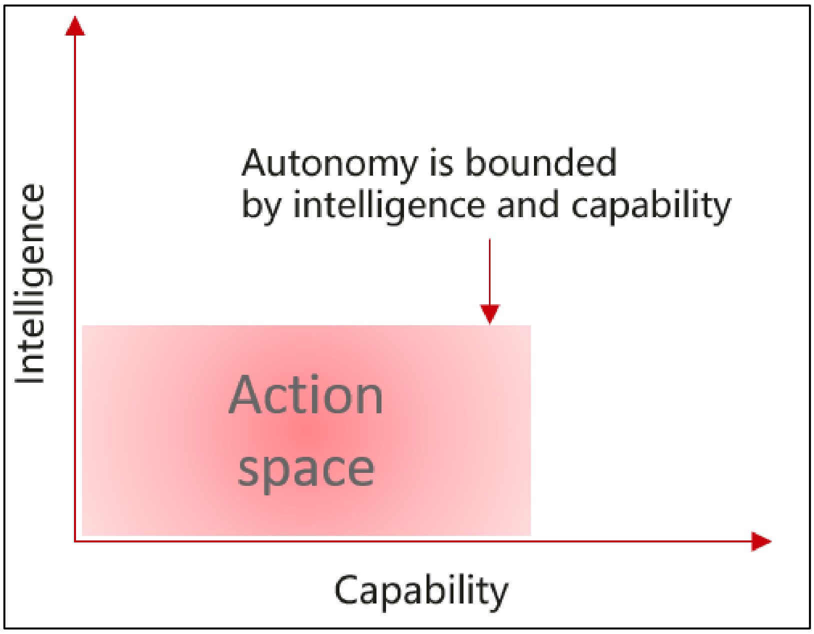

Figure 8 Autonomy: Intelligence versus Capability

To use a simple example: take the case of a robotic lawnmower. These are excellent intelligent products for flat and undulating terrain, but their capability often limits their autonomy, and therefore utility. For gardens that are split level, or non-contiguous, for example, the robotic lawnmower does not have the capability to autonomously move between one area and another - a human must intervene. The lawnmowers autonomy is therefore bounded by its capability.

Thus: system autonomy is best measured as a function of what tasks and operations can be done independently, and what requires human intervention. At a very simplistic level it would be expressed as follows:

$$\frac{\#\ Operations\ that\ don't\ require\ human\ involvement}{\#\ Operations}$$

To enable calculation of such a metric telemetry data is required

- # operations (or tasks undertaken)
- # operations that require human involvement
- # operations that do not require human involvement

These should be available over many dimensions of analysis, such as: time of day, day of week, user ID, domain, operation type, object type, attributes, object instance, vendor, software version.

When SON (self-organizing networks) were introduced by 3GPP in 2010 (and appeared in commercial products subsequently) all configuration changes made by the network were logged alongside human-applied configuration changes, thus it was, in theory, possible to compute what % of configuration changes were made. A similar (but broader) set of telemetry will be needed to measure broader network autonomy.

6.2 Trust and Understandability

For humans to delegate many of their business and network operation responsibilities to a machine they must trust the machine will deliver an equivalent (or even better) business outcome. Without that trust adoption of the AN will be a significant challenge. Trust depends on mutual understanding, that is: a human must first understand the behavior of the AN before they can grow to trust it. The behavior and competence exhibited used by the AN must be appreciated by humans for it to engender trust, and this must be consistent over time. At a high level, trust can be simply defined as follows:

$Trust = \frac{Consistency}{Time}$More practically there are three dimensions to trust that must be considered:

Dependability: the belief that the system will do what it indicates it will do (or what business policies indicate it should do). This largely pertains to metrics that already exist for service availability, reliability, and integrity, but would also include safety (no bad consequences for users or the environment), encompassing confidentiality and security. Competence: the belief that the system has the ability to do what it indicates it will do (or what business policies indicate it should do). It can be assessed by tracking how often (or not) a human agrees with what the AN is suggesting as a course of action. Each recommended course of action should come with an explanation. Satisfaction with the explanation can be measured by collecting human feedback from the user interface. Integrity: the belief that a system is fair and just. This relates to bias, and whether the system exhibits any form of bias towards customers, customer groups, partners, etc. This bias could be explicit (attitudes or beliefs expressed at a conscious level of awareness) or implicit. Human curiosity is also something that should be considered. That is: how do users interact with explanations. This can inform us on the quality of the explanations the system is providing, and whether the mental models used within the explanations are appropriate for users.

Ideally it should be possible to track

- # suggestions made by AN
- # user feedbacks provided on suggested made by AN (satisfactory and unsatisfactory)
- # operations whose underlying logic and output can be accounted for
- % operations of whose underlying logic and output can be accounted for

At a deeper technical level where AI is used AI model inputs and outputs should be tracked to identity irregularities which may indicate bias within an algorithm.

6.3 Deployability

Deployability is a measure of how straightforward a system is to deploy. This could be measured in terms of deployment time (i.e. how long does it take) deployment success rate (i.e. is the deployment 100% successful, or does a human have to intervene to resolve some issues). Naturally when the network is autonomous these metrics should be (1) better than today's more traditional deployment approaches and (2) continuously improving.

The following types of data would, at a minimum, be required from telemetry:-

- Total time to deploy
- Time deployment process had to be paused

- # associated work orders
- # humans involved
- # human operations involved

6.4 Adaptability

Adaptability is a measure of how good a system is at adapting to state changes, whether caused internally, or via the external environment. Whenever major changes occur the AN will, for some amount of time, go into a state of inequilibrium, where it is no longer synchronized with the network. The goal is to return to a state of equilibrium as quickly as possible in order to remain in control. Measurements that matter are

- Time in in-equilibrium: time in which the AN is adjusting to dynamic changes, and therefore is not in complete control
- Time to adapt: time taken for the AN to adjust to the above mentioned changes (e.g. ML models are retrained etc.). In control theory this is called “time to reach accuracy”
- Time between adaptations: time between two adaptations, indicating how robustly the autonomous system (or function) is handling incoming network data. This is akin to a term within machine learning, called 'performance drift'. Drift is about monitoring model KPIs to determine model performance, which may trigger a retraining process if drift has occurred. If incoming network data is dramatically different to the training data which the model has been created, then performance drift often will occur.

6.5 Sustainability

CSPs are significant users of energy and markets generally expect them to report on their usage and how they are reducing their carbon footprint. The AN should help the operator monitor and actively reduce the power consumption and therefore CO_2 emissions. The following types of KPIs are relevant:

- Energy Consumption
- Energy Consumption by source (Fossil fuel, nuclear, solar, wind, EV battery)
- Carbon Footprint (ktons of CO_2)
- Water consumption (for cooling systems, where applicable)

As examples two publicly quoted objectives from Telia and BT, per their annual reports:-

- Telia: be Co_2 neutral and zero waste by 2030
- BT: reduce Co_2 emissions by 87% by 2030

6.6 Consumability

One of the main customer criticisms of CSPs today is that they cannot deliver services quickly and frictionlessly like cloud service providers. In contrast products and services offered by cloud service providers are very "consumable" : customers can easily select what they need, configure it, and it is available for use instantly, or, in the worst case, a few minutes later. With cloud: services have been transformed into the equivalent of utilities. They can be turned on when you need them, and off when you do not.   This is where CSPs need to get to.

Key consumability metrics for a CSP will be

- Time to find product
- Time to order
- Time to service consumption
- Time to customize service
- Time to modify service (e.g. increase or reduce capacity, add more branch offices, etc.)
- Time to cancel
- Number of human interventions required, per transaction (this should be zero, or close to zero, per cloud service providers)

6.7 Resource Efficiency and Utilization

These metrics are not new for ANs but are very important comparatively. An AN should do much better here than a manually operated network, otherwise the business case for AN is not as strong.

6.7.1 Resource Efficiency

Many operators talk about "production cost" or "production cost-per-bit".   The more resource efficient the network the lower the production cost. CSP will want to track how good the AN is at achieving efficiency gains versus a manually operated network.

The AN should be able to do more with less, e.g. if 100 CPUs costing $100K/month are needed to improve a process costing $90K/month by 15% that is not a good result!

Metrics such as the following are relevant

- CPU unit / MB consumed
- Memory unit / MB consumed
- kWH / MB consumed
- <#human minutes expended> / MB consumed

6.7.2 Resource Utilization

This is about understanding how good the AN is at achieving better resource utilization levels. The metrics will focus on resource utilization across CPU, memory, radio frequency.

6.8 Quality of experience

Similar to resource efficiency and utilizations QoE metrics are not new. The AN should deliver better customer perceived quality of experience (QoE) to all applications that use it, and it should be comparably better than a network that is manually operated. This QoE should cover the full lifecycle, using SLAs where required, covering

- Time to order

- Time to set up
- Service outage time
- Time to modify
- Time to repair (in the event of a service outage)
- Standard technical QoS metrics associated with the applications
    - Accessibility and access latency
    - Retainability
    - Throughput
    - Packet loss
    - Latency
- Achieved QoS Rate: QoS is negotiated, customers often get less than they request today. This phenomenon should reduce with the AN based on better resource allocation policies

6.9 Observability Principles

6.9.1 Observability

All components within an AN shall be observable. All domains (and functions within domains) shall produce appropriate data to support SLA monitoring

- automated incident detection and alerting
- analysis of system health (historical trends and analytics)
- manual debugging - when necessary

- “Appropriate data” includes Metrics (standardized and non-standardized performance counters), KPIs (useful for analytics), Logs (useful for behavioral understanding and problem determination purposes), Health check outputs (useful to understand health status of individual components), Tracing (useful for understanding control flow from one domain (or function) to another).

Given that an AN is a heterogeneous environment interoperability in this area is important.

6.9.2 AN key performance indicators

New dimensions of analysis shall be necessary to measure and evaluate the success of ANs. New KPIs shall be specified as part of standardization efforts but nominally the output shall consist of the following KPI categories: autonomy, consumability, trust, sustainability, adaptability and deployability. Many existing KPIs will not change however it is expected AN should improve KPI values over time.

6.9.3 Traceability for audit purposes

The AN shall record all relevant data pertaining to the status of the network and its components, and what events and incidents trigger it to act. This trace shall include references to the responsibility matrix, e.g.

24/8/2020: user JamesOS approved ADN recommended action B to reset base station DublinRBS001A

These traces shall be archived for auditing purposes.

7 Responsibility Principles

As with other sectors the subject of responsibility is an important one for autonomous systems. There are often "gray areas" in this area that cause lots of controversy. Simplistically:

- for an L0 AN system the human carries out all activities and therefore is 100% responsible.
- for an L5 AN system the network (or machine) carries out all activities and therefore is 100% responsible. Idealistic perhaps, but mathematically correct!
- Most networks are somewhere between 0 and 5 and thus responsibility is shared.

The challenge is the percentage of sharing in L1-L4 networks can be very dynamic, and it can be very difficult to track. The following principles are outlined to help with the creation of CSP specific situational awareness mechanisms.

7.1 Responsibilities at first startup of AN

Upon the first startup of the AN autonomous functionality shall be enabled, but not activated[2]. In fact: it will be running in background to learn from human

7.2 Machine and human responsibility

Over time the AN shall independently improve consumability, performance, and efficiency in most common situations however human intervention can be expected to be required for knowledge augmentation, judgement, decision making and execution, especially in "corner" or "edge" cases

Humans shall also perform ongoing monitoring, validation, and audit of the behavior of the AN and its constituent parts (domains)

7.3 Responsibility awareness

The functions and tasks that remain under direct human responsibility must be clear to them at all times. The functions and tasks that are delegated to the AN must be evident to the relevant human(s) at all times, as well as when the status changes.
A dynamic responsibility matrix shall exist for each AN domain and function within a domain (e.g. PASCI or RACI - see definitions)

[2] This is a principle adopted by self-organizing networks (SON) when those capabilities were introduced in LTE.

7.4 Assignment and removal of responsibility

- A suitably authorized human can delegate and remove task responsibilities from the AN at any stage.
- Delegation of tasks may fail (e.g. if the AN is not ready from a state management perspective).
- Removal of responsibility shall not fail in general. However, to ensure the system remains in a consistent and safe state, some transactions may be completed by the machine before it can release responsibility.

7.5 Responsibility handover

In the event the AN detects that it needs to hand over some or all overtake responsibility to a human

- the handover reason(s) shall be clear
- the AN shall request a confirmation that the human has accepted the handover
- if no confirmation is forthcoming the AN shall take steps to secure a safe steady state (there may be some negative consequences), these steps would essentially be heuristics and predetermined rules that are appropriate to the specific scenario. In parallel use a defined communication escalation path to inform appropriate staff that the handover has taken place

8 Autonomy degradation and failure handling principles

If a function or system is autonomous the impact to business outcomes as a consequence of a degradation and failure need to be extremely clear to all involved. In fact: some functions may not be automatable at all if conditions around stability are too difficult to achieve during degraded or failure conditions. The following state machine depicts the general business logic that is needed to ensure stability.

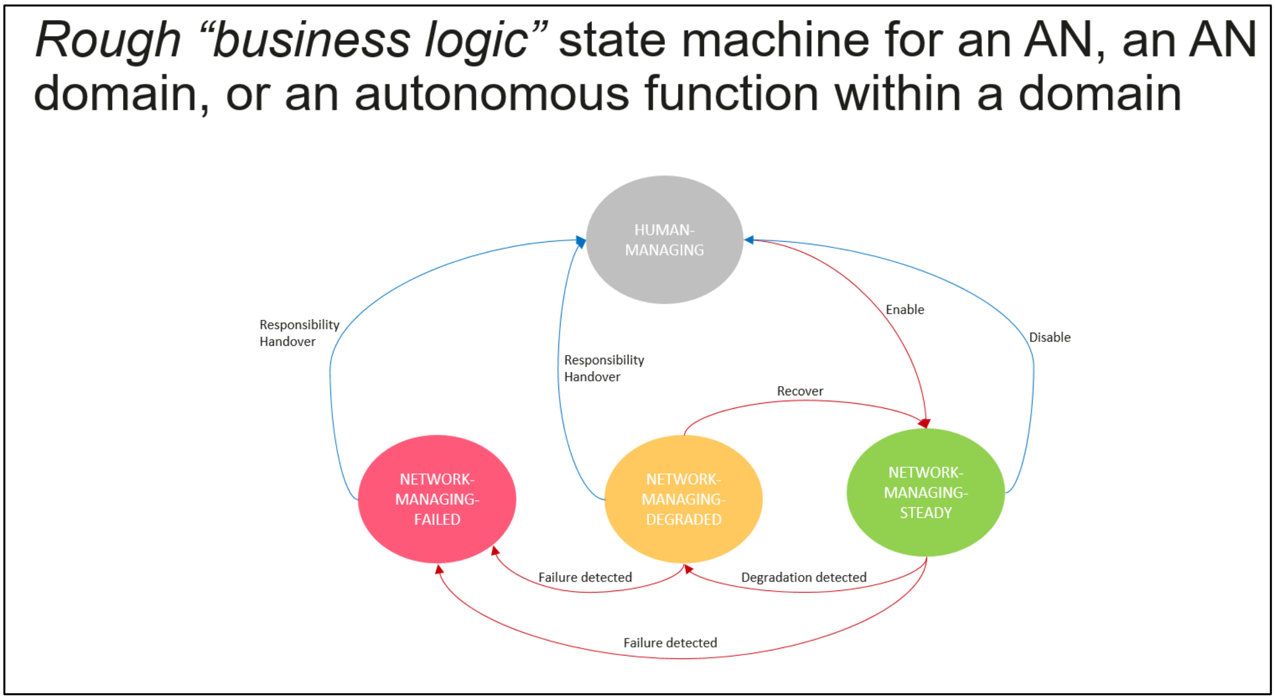

Figure 9 Rough AN business logic state machine

8.1 Degradation of autonomous functionality

In the situation where autonomous functionality degrades the AN shall be aware of the degradation, and report it, but shall still be capable of running the function at reduced [capacity/availability/etc.] levels whilst the degradation is triaged with the help of a human.

8.2 Failure of autonomous functionality

In the situation the autonomous functionality fails, the AN shall be aware of the failure, and control shall be reverted to a human. Procedures to revert the system or functionality to a consistent known state shall exist and be understood by all.

9 Behavior and Explainability Principles

9.1 Indistinguishable behavior of AN from human operated network (analogous to a "Turing test" [3])

The AN shall exhibit behaviors that are consistent with manually operated networks so that all participants within an ecosystem can continue to seamlessly interoperate, as before. Participants include

- Mobile terminals (i.e. UEs)
- Roaming partners
- Internet exchanges
- Interconnection exchanges
- Cloud service providers
- Vertical industries

The full or partial introduction of an AN shall be fully transparent to ecosystem participants.

9.2 Adjusting behavior of an AN

Where “inappropriate” or “incorrect” AN behavior is detected the human shall have the ability to teach and help the network to adjust its behavior. The effect of the adjustment shall typically be gradual.

9.3 Explainable behavior

The behavior of the AN shall be easy-to-understand for [competent] humans

The AN shall be able to explain its behavior and decision making to [competent] humans in terms that they understand

9.4 Predictable behavior

Given the same starting state and set of input events the AN [running a given set of software versions] shall always produce the same result.

[3] Note 1: when ANs communicate to other ANs its highly likely the dialog can be more optimized once the initial preamble exchange takes place.

Note 2: this is not intended to be an official Turing test as not all autonomous functions will be implemented using AI

9.5 Uncertainty estimation

The AN should use uncertainty estimation throughout to ensure only high confidence actions are executed autonomously. The setting for "high confidence" would typically be set as a policy by a human and would vary per use case and scenario.

10 Principles of Human-Machine Interaction (HMI)

Human-machine interaction (HMI) is a crucial element for the safe and stable operation of ANs. As it progresses up the autonomous levels the AN takes on more tasks and the human does less, being freed up to do more strategic work within the business. This often gives rise to the so-called "control problem" [ref 12,13], which is the tendency of the human agent within a human–machine control loop to become complacent, over-reliant or unduly diffident when faced with the outputs of a reliable autonomous system. To paraphrase it in logic:

The control problem occurs when:

[Machine automation fails **OR** degrades to a level that is problematic **]**

AND

[Human does not notice **OR** is incapable of taking over responsibility when needed **]**

Note that this problem is not unique to AI or ML powered automation, it applies to any type of automation implementation.

If AN is 100% reliable in terms of delivering business outcomes then human supervision is not necessary, and thus the control problem will not occur. The reality, however, is that very few automation functions are 100% reliable so some human supervision is still needed. "Almost 100% reliability" is actually the biggest issue:

- Extremely high (but not 100%) reliability engenders complacency in humans, and they often switch off, which means they are not ready to take over if the machine automation encounters an insurmountable problem
- because the automation is so reliable humans do not get to practice many of the normal day-to-day tasks that they performed in the past, thus they slowly become deskilled.

The most important goal for the AN HMI is to secure the users correct interpretation of the network status, and that they understand their responsibilities in the moment of a responsibility transition.

Based on research in other fields (military, aviation, shipping) [ref 13] the appropriate and practical ways to alleviate the control problem are

- Ensure the human still has a meaningful and active role in "policing the automation". This may [counter-intuitively] mean using less reliable technical solutions in some instances to instill greater vigilance in humans. The targeted scenarios may vary per operator, a needs analysis is needed as part of AN solution planning.
- Introduce simulated accountability measures (so called "catch trials") in which system errors are deliberately generated to keep human invigilators situationally aware. This could be quite useful in counteracting automation bias and has been quite successful in the autonomous shipping industry.

On the first alleviation point a pragmatic role partitioning and collaboration strategy is required for each CSP. The general methodology put forward by Accenture principals in [ref 8] may be a good starting point. Figure 10 is a slightly adjusted version adopted from the book, where the central six roles are where true collaboration between humans and machines take place.

Human Only		Human & Machine True Collaboration						Machine Only	
		Human helping machines			Machine helping humans				
Lead	Improvise	Train	Explain	Maintain	Fortify	Interact	Physical aid (robot, cobot)	Iterate	Transact
Create	Judge							Predict	Evolve

Figure 10 Human machine collaboration activities

“Train”, “explain”, and “maintain” are distinct roles that are relevant when dealing with AI or non-AI based automation. The human only and machine only designations are based on who is better and more naturally suited to these items (at least currently – machines may advance in other areas in future).

In summary the AN HMI should be carefully designed to consider the psychological and cognitive traits and states of humans with the goal of optimizing the human’s understanding of the current task/situation and of reducing incorrect system operation. It will not be one-size-fits-all, rather it will be self-adjusting to each CSP environment. Some related principles are outlined below:

10.1 Human-machine interface – human-agent teaming

The AN HMI shall support flexible modes of human-agent teaming, whereby a human (or group of humans) and the network behave as equal partners on a team (but human intervention is still in place, obviously), and collaborate on goals where there is “shared situation awareness” within the team. Shared situation awareness is knowledge about the current state of the task environment, as well as team activities, team performance, dependencies, and overall progression with respect to the team task. Such knowledge shall facilitate coordination and reallocation of tasks within the team but shall also be used for effective and efficient communication inside and outside the team members.

10.2 "Flight simulator" mode

As the ANs gets increasingly automated there will be less work for the user to do (in terms of traditional tasks at least). On a similar vein some parts of the network are increasingly reliable, and many error scenarios are not seen regularly, if ever! (i.e. extremely rare). The result of these situations is that humans could become deskilled over time because they are not actively doing the work as they did in the past. The AN should support "flight simulator" style drills in a sandbox or simulation environment to help them maintain their skills and prepare for "chaos monkey" scenarios that, generally speaking, would not normally be experienced. This also helps address the control problem associated with all automated systems.

10.3 User profiles to better optimize human:machine collaboration

To account for the fact that, just like the network, humans change over time (skills, abilities, connections, etc.) and better enable human collaboration the AN should build targeted profiles or annotations of users to understand their technical and operational competences, abilities, and strengths, and their workplace related "social" network. Such profiles are useful for task/work allocation, ad hoc team formation, user behavioral analysis (to build strong machine learning models, for example), and bias detection.

10.4 Human-machine interface presentation of information

To [eventually] reach level 4 and 5 autonomous levels the HMI of the AN should generally only display information for which a human consultation (or decision) is necessary. Presentation of unnecessary information [for the task at hand] should be avoided as much as possible to avoid high cognitive load on the human which ultimately negatively impacts decision making.
Note: this may not be achievable from the outset, but it should be a goal, and there should be a plan on how to achieve it

10.5 Human-machine interface multi-modality (AN ↔ network operator domain experts)

To cater for increased customer diversity and the ongoing trend in application mobilization the AN HMI shall cater for different usage and modes of interaction. The traditional telco "big screen" model of network operations is not a suitable HMI for many enterprises, and majority of CSPs are mobilizing many of their systems. Where it makes practical sense and improves human-machine collaboration mobile and AI assistants shall be available for some applications and use cases. Removal of human bottlenecks

Background: In today's network operations many things do not happen because humans fail to do them, due to other work, absence, or some other reason. For example: the organizations priorities were incorrect because John was out sick this morning - he did not login and run the Wireless status report.

All human bottleneck tasks should be found and delegated to the ANs, and the workflow/process redesigned to ensure human bottlenecks are entirely removed.

Vendor product offerings should be evaluated on how many (or few) human bottlenecks their products introduce.

10.6 Transformation of product documentation into digital knowledge assets

Humans shall not need to refer to individual product documentation for daily network operations, the AN should inform them what they need to know in any given context
Product documentation concerning features, capabilities, and dependencies shall be manifested as machine readable artifacts for use by the autonomous, which shall actively use them as knowledge assets.

Documentation concerning differences between network function product versions (software and hardware) shall be manifested as machine readable artifacts in order for use by the AN to actively use these facts as knowledge assets, removing painstaking and error prone investigation tasks from humans. Note: some traditional network node product documentation shall still have a role for network planners and technical staff involved in procurement evaluation processes.

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12 Administrative

12.1 Document History

12.1.1 Version History

Version Number	Date Modified	Modified by:	Description of changes
0.1	09-Jul-2020	James O'Sullivan	Initial Version (Confluence)
0.2	10-Aug-2020	Kevin McDonnell	Converted to a formal GB template
0.3	25-Aug-2020	James O'Sullivan	Updated, reoriented some content to reflect change from a section to an independent document. Made available on TMF confluence page.
0.4	26-Aug-2020	James O'Sullivan	Improved HMI section.
0.5	27-Aug-2020	James O'Sullivan	Incorporating Kevin comments
0.6	27-Aug-2020	Kevin McDonnell	Updates to Diagrams and Appendixes
0.7	31-Aug-2020	James O'Sullivan	Accepting many of edits. Split production factors diagram in two – too small previously.
1.0.0	02-Oct-2020	Alan Pope	Final edits prior to publication in 2020 Sprint 5

12.1.2 Release History

Release Status	Date Modified	Modified by:	Description of changes
Pre-production	02-Oct-2020	Alan Pope	Initial Release
Production	24-Nov-2020	Adrienne Walcott	Updated to reflect TM Forum Approved Status

12.2 Acknowledgments

This document was prepared by the members of the TM Forum ANs project:

- James O'Sullivan (Author, Huawei)
- Kevin McDonnell (Contributor, Huawei)
- Azahar Machwe (Contributor, BT)
- Dave Milham (Contributor, TM Forum)

12.3 Contributions

Summary	Reporter	Key
Integrated Human:Machine system for AN	James O'Sullivan	ANP-79
Investment and wealth management industries - learnings for ANing	James O'Sullivan	ANP-78
AN demo mockup to illustrate some of the collaborative principles the AN needs to support	James O'Sullivan	ANP-61
Input for business/technical guiding principles	James O'Sullivan	ANP-59
Observability: measuring the AN	James O'Sullivan	ANP-47
Defining AN Interaction with Humans and Other AN Systems	Azahar Machwe	ANP-74
AN Guiding Principles - diagrams	Kevin McDonnell	ANP-110

13 Appendix I: AN Guiding Principles

The following table provides a short tabular view of the complete list of guiding principles.

Table 1 Complete list of Guiding Principles.

#	Category	Principle
0	Business driver	Scope "Everything" within the AN shall not need to be fully (or even partially) autonomous, it may not be justified from a business perspective. This is an overarching principle to remind us that it is extremely unlikely (or even infeasibly) that, pragmatically, every single part of the CSP business will not be fully autonomous. In fact, in some cases, too much autonomous may be counterproductive, and create more issues than it resolves. Per ref [7] the performance of the human-machine system increases with the autonomy of the machine, but only until some optimum, after which it decreases. That is because if the autonomy of the machine is further increased, the human operator is likely to lose control of the situation, and things then regress, as shown on below.
The following will differ in priority for each CSP depending on the type, size, and goals of the business		
1	Business driver	Customer experience Customer experience shall, for most CSPs, be a driving factor when considering and deciding how autonomous a function or domain should be. The focus shall be on how customer is going to experience the product (or service) provided by the network and what happens if it fails or degrades. Focusing on these scenarios shall drive out the right autonomous behaviors.
2	Business driver	Cost of operation Cost of sustainment (or cost to operate) shall drive the need to implement autonomous behavior. Generally, functions that are more costly and onerous to operate should be prioritized over ones that are less costly. The AN shall help the CSP deliver products and services at lower per unit costs, maximize the utilization of their assets, and minimize waste.
3	Business driver	Speed of operation Speed of operation shall drive the need to implement autonomous behavior. Functions that are slow, or that regularly become bottlenecks, are obvious candidates to target for some (or full) autonomy. The AN shall help the CSP reduce execution times across all tasks and disciplines: service design and creation, network rollout, service, network, and customer provisioning, assurance, billing, rating, migrations, service retirement, etc.
4	Business driver	Reliability of operation Reliability (or dependability) shall drive the need to implement autonomous behavior. Reliability means doing things in time so that customers to receive the right set of products and services exactly when they are needed, or at least when they were promised. Over the long term being reliable translates into time and cost savings, improving the business reputation, and ultimately increasing future revenue potential. The AN shall help the CSP become more reliable.
5	Business driver	Quality of operation Quality is consistent conformance to customers (and partners and regulators) expectations - in other words "doing things right", "doing things right" shall drive the need for autonomous behavior. In some ways, quality is the most visible part of what a CSP does from a customer perspective, and thus is related to guiding principle #1, but quality is about more than customer experience. The AN shall help the CSP deliver error-free products and services which are 'fit for purpose'.

#	Category	Principle
6	Business driver	Flexibility of operation to make changes Flexibility of operation shall drive the need to implement autonomous behavior. Today customers demand greater flexibility in the following ways: • product/service flexibility – ability to introduce new or modified products and services • product/service mix flexibility – ability to produce a wide range or mix of products and services • volume flexibility – ability to change level of output or activity to support different product volumes, or capacities • delivery flexibility – ability to change the timing of delivery of services and products. The AN shall help the CSP become more flexible to customers changing needs.
7	Business driver	Risk of business discontinuity Risk of business discontinuity shall drive the need to implement autonomous behavior. Business discontinuity can happen for several reasons; examples would be IT security attacks, or organizational competence gaps (e.g. due to CSP staff aging demography, or faster pace of technological change). The AN shall enable the CSP to have more robust business continuity plans and procedures.
8	Observability	Observability The AN shall be observable. All domains (and functions within domains) shall produce appropriate data to support • automated incident detection and alerting • analysis of system health (historical trends and analytics) • manual debugging - when necessary "Appropriate data" includes • Metrics (standardized and non-standardized performance counters, KPIs - useful for analytics) • Logs (useful for behavioral understanding and problem determination purposes) • Health check outputs (useful to understand health status of individual components) • Tracing(useful for understanding control flow from one domain (or function) to another) Given that an AN shall be a heterogeneous environment interoperability in this area shall be important
9	Observability	AN key performance indicators New dimensions of analysis shall be necessary to measure and evaluate the success of ANs. New KPIs shall be specified as part of standardization efforts but nominally the output shall consist of the following KPI categories: autonomy, consumability, trust, sustainability, adaptability and deployability.
10	Observability	Traceability for audit purposes The AN shall record all relevant data pertaining to the status of the network and its components, and what events and incidents trigger it to act. This trace shall include references to the responsibility matrix (e.g. user JamesOS approved ADN recommended action B to reset base station DublinRBS001A) These traces shall be archived for auditing purposes.
11	Responsibility	Responsibilities at first startup of AN Upon the first startup of the AN autonomous functionality shall be enabled,

#	Category	Principle
		but not responsible**. In fact: it will be running in background to learn from human ** This is a principle adopted by self-organizing networks (SON) within wireless networks today.
12	Responsibility	Machine and human responsibility Over time the AN shall independently improve consumability, performance, and efficiency in most common situations however human intervention shall still be required for • knowledge augmentation, judgement, decision making and execution, especially in ”corner” or “edge” cases • monitoring, validating, and auditing the behavior of the AN and its constituent parts (domains)
13	Responsibility	Responsibility awareness The functions and tasks that remain under human responsibility must be clear to them at all times. The functions that are under the responsibility of the autonomous must be evident to the relevant human(s) at all times, as well as when the status changes. A responsibility matrix shall exist for each AN domain and function within a domain (e.g. PASCI or RACI - see definitions)
14	Responsibility	Assignment and removal of responsibility • A suitably authorized human can assign and remove responsibilities from the AN at any stage. • Assignment of responsibility may fail (e.g. if the AN is not ready from a state management perspective). • Removal of responsibility shall not fail in general. However, to ensure the system remains in a consistent and safe state, some transactions may be completed by the machine before it can release responsibility.
15	Responsibility	Responsibility handover In the event the AN detects that it needs to hand over some or all over responsibility to a human • the handover reason(s) shall be clear • the AN shall request a confirmation that the human has accepted the handover • if no confirmation is forthcoming the AN shall take steps to secure a safe steady state (there may be some negative consequences), and in parallel use a defined communication escalation path to inform appropriate staff that the handover has taken place
16	Degradation and failure	Degradation of autonomous functionality In the situation where autonomous functionality degrades the AN shall be aware of the degradation, and report it, but shall still be capable of running the function at reduced [capacity/availability/etc.] levels whilst the degradation is triaged with the help of a human.
17	Degradation and failure	Failure of autonomous functionality In the situation the autonomous functionality fails, the AN shall be aware of the failure, and control shall be reverted to a human. Procedures to revert the system or functionality to a consistent known state shall exist and be understood by all.
18	Behavior and explainability	Indistinguishable behavior of an AN (like “Turing test”) The AN shall exhibit behaviors that are consistent with manually operated networks so that all participants within an ecosystem can continue to seamlessly interoperate, as before. Participants include • Mobile terminals (i.e. UEs) • Roaming partners • Internet exchanges • Interconnection exchanges

#	Category	Principle
		• Cloud service providers • Vertical industries The introduction of an AN shall be fully transparent to ecosystem participants
19	Behavior and explainability	<u>Adjusting behavior of an AN</u> Where “inappropriate” or “incorrect” AN behavior is detected the human shall have the ability to teach and help the network to adjust its behavior. The effect of the adjustment shall typically be gradual.
20	Behavior and explainability	<u>Explainable behavior</u> The behavior of the AN shall be easy-to-understand for [competent] humans The AN shall be able to explain its behavior and decision making to [competent] humans in terms that they understand
21	Behavior and explainability	<u>Predictable behavior</u> Given the same starting state and set of input events the AN shall always produce the same result
22	Human machine interface	<u>Human-machine interface multi-modality (Autonomous network ↔ network operator domain experts)</u> To cater for increased customer diversity and the ongoing trend in application mobilization the autonomous network HMI shall cater for different usage and modes of interaction. The traditional telco “big screen” model of network operations is not a suitable HMI for many enterprises, and majority of CSPs are mobilizing many of their systems. Where it makes practical sense mobile and AI assistants, or conversational agents shall be available for some applications and use cases. The challenge is to support bidirectional transparency in real time, while not overwhelming the human with too much information and burden
23	Human machine interface	<u>Human-machine interface – human-agent teaming</u> The AN HMI shall support flexible modes of human-agent teaming, whereby a human (or group of humans) and the network behave as equal partners on a team (but human intervention is still in place, obviously), and collaborate on goals where there is “shared situation awareness” within the team. Shared situation awareness is knowledge about the current state of the task environment, as well as team activities, team performance, and overall progression with respect to the team task. Such knowledge shall facilitate coordination and reallocation of tasks within the team but shall also be used for effective and efficient communication among the team members.
24	Human machine interface	<u>Human-machine interface presentation of information</u> To [eventually] reach level 4 and 5 autonomous levels the HMI of the AN should generally only display information for which a human consultation (or decision) is necessary. Presentation of unnecessary information [for the task at hand] should be avoided as much as possible to avoid overwhelming the human and negatively impact decision making. Note: this may not be achievable from the outset, but it should be a goal, and there should be a plan on how to achieve it
25	Human machine interface	<u>Removal of human bottlenecks</u> Background: In today’s network operations many things do not happen because humans fail to do them, due to other work, absence, or some other reason. For example: the organizations priorities were incorrect because John was out sick this morning - he did not login and run the Wireless status report. All human bottleneck tasks should be found and delegated to the ANs, and the workflow/process redesigned to ensure human bottlenecks are entirely removed. Vendor product offerings should be evaluated on how many (or few) human bottlenecks their products introduce.

#	Category	Principle
26	Human machine interface	<u>"Flight simulator" mode</u> As the ANs gets increasingly automated there will be less work for the user to do (in terms of traditional tasks at least). On a similar vein some parts of the network are increasingly reliable, and many error scenarios are not seen regularly, if ever! (i.e. extremely rare). The result of these situations is that humans could become deskilled over time because they are not actively doing the work as they did in the past. The AN should support "flight simulator" style drills in a sandbox or simulation environment to help them maintain their skills and prepare for "chaos monkey" scenarios that would not normally be experienced.
27	Human machine interface	<u>User profiles to better optimize human:machine collaboration</u> To account for the fact that, just like the network, humans change over time (skills, abilities, etc.) and better enable human collaboration the AN should build targeted profiles of users to understand their technical and operational competences, abilities, and strengths. Such profiles are useful for task/work allocation, ad hoc team formation, user behavioral analysis (to build strong machine learning models, for example), and bias detection.
28	Human machine interface	<u>Transformation of product documentation into digital knowledge assets</u> Humans shall not need to refer to individual product documentation for daily network operations, the AN should inform them what they need to know in any given context Product documentation concerning features, capabilities, and dependencies shall be manifested as machine readable artifacts for use by the autonomous, which shall actively use them as knowledge assets. Documentation concerning differences between network function product versions (software and hardware) shall be manifested as machine readable artifacts in order for use by the autonomous network to actively use these facts as knowledge assets, removing painstaking and error prone investigation tasks from humans Traditional network node product documentation shall still have a role for network planners and technical staff involved in procurement evaluation processes.

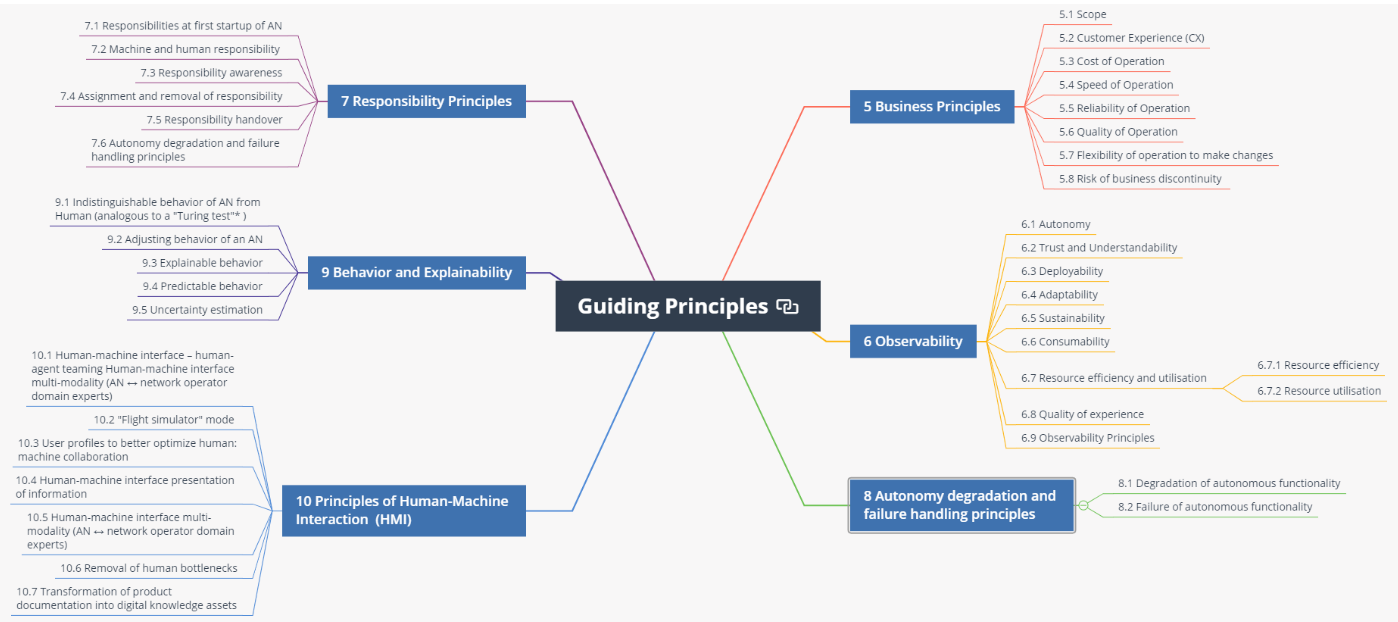

Figure 11 Guiding principles detailed

14 Appendix II: Map of Guiding Principles

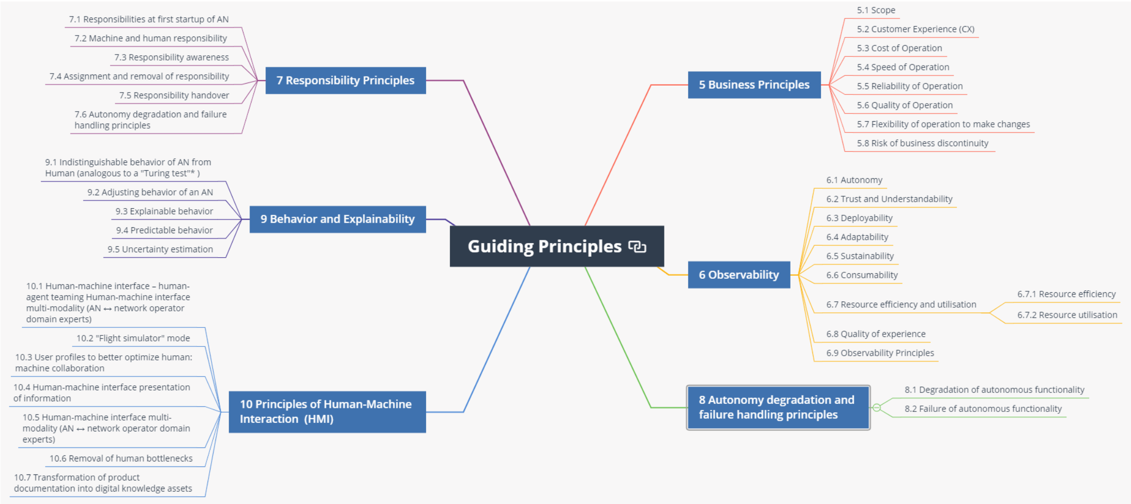

Figure 12 Guiding Principles

Table 2 Guiding Principles Quick Reference

Guiding Principles					
5 Business Principles	**6 Observability**	**7 Responsibility Principles**	**8 Autonomy Degradation and Failure Handling Principles**	**9 Behavior and Explainability**	**10 Principles of Human-Machine Interaction (HMI)**
5.1 Scope	6.1 Autonomy	7.1 Responsibilities at first startup of AN	8.1 Degradation of autonomous functionality	9.1 Indistinguishable behavior of AN from Human (analogous to a " Turing test"*)	10.1 Human-machine interface – human-agent teaming
5.2 Customer Experience (CX)	6.2 Trust and Understandability	7.2 Machine and human responsibility	8.2 Failure of autonomous functionality	9.2 Adjusting behavior of an AN	10.2 "Flight simulator" mode
5.3 Cost of Operation	6.3 Deployability	7.3 Responsibility awareness		9.3 Explainable behavior	10.3 User profiles to better optimize human: machine collaboration
5.4 Speed of Operation	6.4 Adaptability	7.4 Assignment and removal of responsibility		9.4 Predictable behavior	10.4 Human-machine interface presentation of information
5.5 Reliability of Operation	6.5 Sustainability	7.5 Responsibility handover		9.5 Uncertainty estimation	10.5 Human-machine interface multi-modality (AN ↔ network operator domain experts)
5.6 Quality of Operation	6.6 Consumability	7.6 Autonomy degradation and failure handling principles			10.6 Removal of human bottlenecks
5.7 Flexibility of operation to make changes	6.7 Resource efficiency and utilisation				10.7 Transformation of product documentation into digital knowledge assetsdocumentation
5.8 Risk of business discontinuity	6.8 Quality of experience				
	6.9 Observability Principles				