

Effects of Bottlenecks within Military Training Pipelines

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ABSTRACT

Military human resources (HR) systems must generate and sustain the human capability that underpins fighting power. Training pipelines, pathways comprising sequences of courses and activities undertaken by personnel to develop necessary skills, are essential components of military HR systems. However, Western military organisations including the UK Armed Forces have experienced persistent shortages of personnel in some skilled cadres leading to severe human capability challenges. Various initiatives have aimed to rectify skills shortages but these have usually taken little account of the dynamics of military training pipelines. Moreover, the literature includes few studies of military training pipelines and defence policy provides only very broad guidance on training pipeline management without precisely defining important terminology. Neither the presence nor the effects of bottlenecks in training pipelines are adequately acknowledged in the literature or in current defence training or personnel policy.

Harrington et al. (2017) assert that supply chain management literature could be applied to training pipeline management to help improve the flow of personnel through training systems. Accordingly, this paper synthesises Theory of Constraints, a mature systems-based management philosophy that has profoundly influenced modern supply chain management, with the human capability and military training pipeline literature. Drawing upon publicly available sources including government reports the paper examines how training pipelines contribute to the provision of human capability as important sub-systems within broader military HR systems and characterises the nature and effects of bottlenecks that occur within military training pipelines. From this, the paper develops principles to inform and guide the development of defence policy for training pipeline management and presents recommendations on identifying and managing bottlenecks to regulate the flow of personnel through training and improve the provision of human capability.

ABOUT THE AUTHOR

Lieutenant Commander Robert Floyd joined the Royal Navy in 2003 and has held various training and personnel related roles including as a member of the officer candidate selection board, teaching and managing training within shore training establishments and analysing training requirements. He has supported learning and development in warships at sea, provided training system consultancy and advisory support to maritime equipment acquisition projects, and served as the training policy desk officer within Navy Command HQ. He holds a bachelor's degree in Physics with Communications Technology (University of Bath, 2003), a postgraduate diploma in Training Management and Consultancy (University of Portsmouth, 2010) and a master's degree in Defence Acquisition Management (Cranfield University, 2017). He was a co-author of the Royal Navy's Maritime Training Strategy (2018) and is presently serving as the Requirements Manager for a training services outsourcing project.

Keywords: Theory of Constraints; training pipeline; human capability; bottleneck; training system.

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INTRODUCTION

This paper begins by examining the concept of human capability and its relationship to, and dependencies upon, military HR systems and training pipelines. The UK's military training pipelines are outlined and existing training pipeline management policies are discussed. Bottlenecks and flow through supply chains are then discussed from the perspective of Theory of Constraints (TOC), a systems approach to management. A review of the publicly available literature addressing human capability, including government reports, is undertaken to evaluate the present performance of military training pipelines. Although few studies have focused on military training pipelines, relevant examples are reviewed, including the small sub-set of studies that acknowledge the presence or effects of bottlenecks.

This paper then addresses the gap in the literature by characterising the nature and effects of bottlenecks that occur within military training pipelines, before synthesising TOC with reported effects and outcomes from the human capability and training pipeline literature to develop principles to inform and guide the development of defence policy for training pipeline management, and presenting recommendations on identifying and managing bottlenecks to regulate the flow of personnel through training and improve the provision of human capability.

HUMAN CAPABILITY, HUMAN RESOURCES AND TRAINING PIPELINES

“Fighting power is built upon human capability. Human capability is the collective impact that people have on an enterprise. Human capability underpins Defence’s professionalism, and comprises the valuable skills, knowledge and experience possessed by our people, including those contractors and partners with whom we operate; it provides the decisive edge.”

JDP0-01: UK Defence Doctrine (UK Ministry of Defence, 2014, p. 26)

The purpose of a Human Resources (HR) function is to enable an organisation to deliver its corporate strategy and objectives by effectively recruiting and developing people and managing their performance (Chartered Institute of Personnel and Development, 2018). For military organisations, attracting recruits and developing them into skilled, motivated personnel who can be appropriately employed and retained in service depends on crafting and implementing effective personnel policies covering pay, benefits, training, career paths, promotion and pensions. (Williams & Gilroy, 2006).

Human Capability and Defence Outputs

The UK Defence Framework identified two high-level outputs for the Ministry of Defence (MOD): “*Defence policy, comprising the definition of the military capability and other objectives required of Defence to meet the Government’s overall policy aims within planned resources; and military capability needed to deliver Defence policy and to support wider Government policy objectives*” (UK Ministry of Defence, 2010, p. 2). It should be noted that the Framework was superseded by a Defence Operating Model (UK Ministry of Defence, 2015) which, while building on and evolving the concepts of how Defence works, no longer explicitly describes what Defence is and what it is for. Military capability as defined by the MOD comprises eight interdependent ‘Defence Lines of Development’ (DLODs): Training, Equipment, Personnel, Information, Doctrine and Concepts, Organisation, Infrastructure and Logistics, with an overarching theme of Interoperability (UK Ministry of Defence, 2019). As human capability comprises “*the valuable skills, knowledge and experience possessed by our people*” (UK Ministry of Defence, 2014, p. 26) and training is the predominant (but not the only) mechanism for ensuring individual military personnel acquire and maintain the necessary knowledge, skills and attitudes for their employment (UK Ministry of Defence, 2018b) the Training and Personnel DLODs, defined below, are strongly interdependent activities and relate directly to both HR and human capability:

- Personnel DLOD (PLOD) - The timely provision of sufficient, capable and motivated personnel to deliver Defence outputs, now and in the future.
- Training DLOD (TLOD) - The provision of the means to practise, develop and validate, within constraints, the practical application of a common military doctrine to deliver a military capability.

The PLOD is an enabler of both military capability and Defence policy, including definition of requirements and management activities within the PLOD itself and also within the TLOD. Although the generation of human capability requires an integrated approach spanning and including the Civil Service and contractors (UK Ministry of Defence, 2014), this paper will focus on the provision of capable and motivated military personnel to deliver military capability. The UK Armed Forces rely on a ‘base-fed’ personnel model which recruits people into the lowest ranks and successively promotes them as their skills and experience develop (House of Commons Public Accounts Committee, 2018). This creates a pyramidal rank structure and allows the Armed Forces to set out clear career paths but at the cost of taking many years to develop more senior and experienced personnel (UK National Audit Office, 2018).

Training Pipelines

“At Phases 1 and 2, pipeline management ensures that sufficient personnel of the correct branches and/or trades enter training, and subsequently single Services, as Gains to Trained Strength (GTS) in order to meet the manpower requirement of each Service, as outlined in their Service Manpower Plans. At Phase 3, pipeline management ensures that the correct numbers of personnel enter training to sustain the requirements of each branch and/or trade.”- definition of Pipeline Management (UK Ministry of Defence, 2018b, p. 166).

Ab initio recruits to the UK Armed Forces complete common individual basic military skills (‘Phase 1’) training and then progress to initial individual technical and specialist (‘Phase 2’) training (Figure 1). Although this progression is commonly referred to as the ‘training pipeline’ the term is not explicitly defined: instead UK Defence training policy defines ‘pipeline management’ and describes some of the associated governance bodies and processes (UK Ministry of Defence, 2018b). This paper will use the term ‘initial training pipeline’ to mean the progression from recruitment, through Phase 1 and Phase 2 training, to joining the trained strength for personnel in a given branch or trade. As there are many different branches and trades there are actually multiple initial training pipelines of varying duration (Figure 1). The metaphor of a pipeline implies linear progression through training and invokes imagery of particles flowing through a mechanical system.

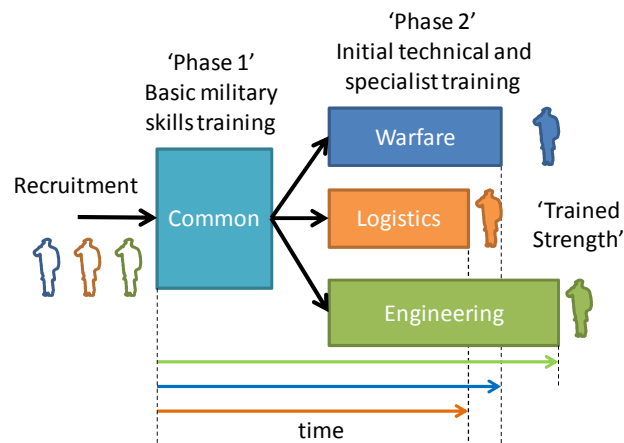


Figure 1: Simplified generic initial training pipelines.

Customer Executive Boards (CEB) are mandated to manage training pipelines (UK Ministry of Defence, 2018a); arguably to fulfil this duty they must coherently integrate the PLOD and TLOD. CEBs should bring together representatives of Training Requirements Authorities (TRA) acting as the ‘customers’ for capable personnel, and Training Delivery Authorities (TDA) who act as the ‘suppliers’ of trained personnel (UK Ministry of Defence, 2018a). Among other responsibilities, CEBs are expected to “ensure the optimisation of training, including the efficiency of training pipelines” (UK Ministry of Defence, 2018a, p. 30).

While efficient training pipelines are intuitively desirable, ‘pipeline efficiency’ and associated metrics are not precisely defined. Guidance states “Pipeline management should be as efficient as possible to ensure that trainees move without significant delay from one phase of training to the next. Holding between training activities should be kept to a minimum as delays adversely affect the individual, and are cost and resource inefficient. Delays also have

a negative impact on Defence effect.” (UK Ministry of Defence, 2018b, p. 61) but offers little guidance on how this can or should be achieved. The limited guidance and lack of definitions allows stakeholders to view pipeline efficiency from different perspectives.

A Service person’s training does not end when they join the trained strength and proceed to their first employment. Virtually all personnel will undertake further training (‘Phase 3’) which may prepare them for specialist employment, qualify them to operate or maintain specific equipment, refresh perishable or important skills (either generic or specialist) or, when they are selected for promotion, prepare them to assume the increased technical and leadership responsibilities of higher rank. However, as the portfolio of Phase 3 training is considerably more diverse than the initial training pipelines, validity of the pipeline metaphor starts to break down at Phase 3: rather than taking well-defined linear pathways through training in relatively large cohorts, individuals’ training needs tend to be dominated by their specific career stage and the employment they are assigned to. Personnel are usually assigned to Phase 3 training from employment or are temporarily stood down from their normal duties. The metaphor of a network, with many possible pathways and with common training modules shared by different pathways and audiences, is arguably more appropriate.

Phase 3 training is undertaken by personnel with more experience and accumulated skills, and who will make more significant contributions to military capability in their employment, than personnel within initial training pipelines or newly joining the trained strength. Training providers often share training resources between courses and across Phases. Moreover, while UK Defence training policy emphasis is on ensuring the ‘correct’ number of people enter Phase 3 training, the aim of the PLOD is only achieved when personnel with the necessary skills are delivered to employment that enables Defence outputs. Therefore successful Phase 3 training pipeline management requires co-ordination and collaborative working between training providers and branch management and career management functions.

As shown in this section, initial training pipelines are the sequenced training activities that prepare *ab initio* recruits for their initial military employment and prepare personnel already on the trained strength for further, more demanding employment. Training pipelines span, and should integrate, the PLOD and TLOD and act as an interdependent network of supply chains providing skilled personnel. Training pipelines must be coherently managed and co-ordinated to provide the necessary profile of skilled personnel for human capability and to deliver Defence outputs. Training pipelines are therefore essential sub-systems within military HR systems that aim to generate and sustain the human capability that underpins fighting power.

THEORY OF CONSTRAINTS, BOTTLENECKS AND SUPPLY CHAINS

“...the prevailing notion that ‘more is better’ is correct only for the constraints, but it is not correct for the vast majority of the system elements – the non-constraints. For the non-constraints, ‘more is better’ is correct only up to a threshold, but above this threshold more is worse.”(Goldratt, 2010, p. 4)

Theory of Constraints

Theory of Constraints (TOC) is a prescriptive and practitioner-focused systems approach to management pioneered by E.M. Goldratt and developed through distinct ‘eras’ (Watson, Blackstone, & Gardiner, 2007) to a level of maturity where Naor, Bernades, & Coman (2013) concluded TOC satisfies the criteria of a good theory. TOC asserts that the ability and capacity of organisations to fulfil their purpose is dominated by a small number of constraints; successful management of the organisation depends on taking account of these constraints (Techt, 2015). TOC has influenced contemporary supply chain management (SCM) to the extent that it is recognised among foundational supply chain concepts by SCM professional bodies (i.e. Eshkenazi, 2012).

In 1979 a request for help from a factory-owner neighbour led to Goldratt developing Optimised Production Technology (OPT), a scheduling system and associated software based around production schedules for ‘bottleneck resources’ whose capacity is equal to or less than the demand placed upon them. OPT quickly tripled the plant’s output with negligible investment (Watson et al., 2007). OPT proved a logical method but not an intuitive one: it was often subverted by workers who did not understand it so *The Goal* (Goldratt & Cox, 1984), a ‘business novel’, was published to explain the underlying principles. *The Goal* condensed the OPT bottleneck-oriented rules into a more concise and generic form (Table 1). TOC advocates precisely articulating the organisation’s overarching

purpose (or Goal) and any Necessary Conditions that must be fulfilled to realise the Goal (Dettmer, 1997; Goldratt & Cox, 1984). TOC also precisely defines three key ‘global operational measurements’ that together allow progress to toward the organisation’s Goal to be measured (Goldratt & Fox, 1986):

- Throughput - The rate at which the system generates money through sales (money coming in)
- Inventory - All the money the system invests in things the system intends to sell (money tied up within)
- Operating Expense - All the money the system spends to turn Inventory into Throughput (money going out)

The original definitions of TOC’s operational measurements are predicated on a profit-making organisation whose de facto purpose is to make money now and in the future. Dettmer (1997) offers adapted definitions of the global operational measurements for non-profit organisations, including military organisations: Throughput becomes the rate at which the system generates value for stakeholders.

Improvement requires increasing Throughput, which should be the highest priority, while simultaneously reducing Inventory (the secondary priority) and Operating Expense (lowest priority). True solutions are packages of measures rigorously designed, implemented, monitored and adjusted to achieve these effects (Dettmer, 1997; Goldratt & Cox, 1984; Techt, 2015).

Table 1: OPT rules and the five TOC focusing steps.

The nine OPT rules (Goldratt & Fox, 1986; Watson et al., 2007)	The 5 focusing steps (Goldratt & Cox, 1984)
<ol style="list-style-type: none"> 1. Balance flow, not capacity. 2. Level of utilisation of a non-bottleneck is determined not by its own potential but by some other constraint in the system. 3. Utilisation and activation of a resource are not synonymous. 4. An hour lost at a bottleneck is an hour lost for the total system. 5. An hour saved at a non-bottleneck is just a mirage. 6. Bottlenecks govern both Throughput and Inventory in the system. 7. A transfer batch may not, and many times should not, be equal to the process batch. 8. The process batch should be variable, not fixed. 9. Schedules should be established by looking at all of the constraints simultaneously. Lead times are a result of a schedule and cannot be predetermined. 	<ol style="list-style-type: none"> 1. Identify the constraint 2. Exploit the constraint 3. Subordinate all other activities to the constraint 4. Elevate the constraint 5. Return to step 1: do not let inertia become the new constraint

Bottlenecks, Throughput and Inventory

Bottlenecks are naturally occurring phenomena in mechanistic systems and will emerge in any chain of dependent events such as a sequence of processes (Goldratt & Cox, 1984); they govern Inventory and Throughput (OPT Rule 6) as illustrated using hypothetical open hourglasses in Figure 2. Once the flow rate reaches the maximum capacity of the bottleneck, increasing input to either the single (a) or serial (b) hourglasses in Figure 2 will not increase Throughput but will increase Inventory. If one was to follow a single particle and time its passage through the serial hourglasses (b), the time that particle takes to pass right through (‘lead time’) will increase proportionally to Inventory due to the ‘queue’ time spent waiting to pass through the bottleneck.

If one were to cease adding input then the greater the level of Inventory, the longer particles already within the system will continue to flow out – although if the output cannot be ‘sold’, or be used to generate value for key stakeholders of a non-profit organisation, this will not count as Throughput and will remain as Inventory. This illustrates how adding more input to a sequence of processes whose bottleneck is overloaded will increase Inventory, increase lead time and reduce responsiveness. If the bottleneck were to become temporarily blocked or its capacity reduced, the Throughput lost during that time could not be caught up (unless the bottleneck’s capacity was subsequently expanded) and would be permanently lost. If input continued to be added, Inventory would continue to increase (Goldratt & Cox, 1984). TOC highlights that the costs associated with excess Inventory are significant and

usually exceed marginal Operating Expense; this justifies the prioritisation of minimising Inventory over reducing Operating Expense.

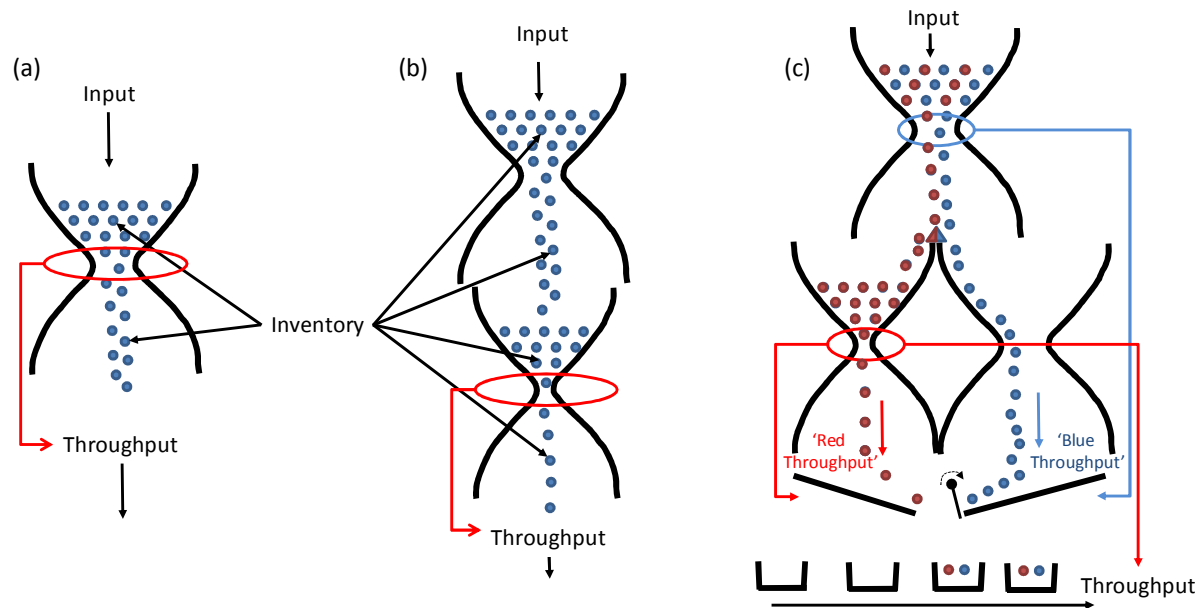


Figure 2: Bottlenecks governing Throughput and Inventory in (a) single, (b) serial and (c) parallel processes.

Throughput focus vs local optimisation

A core principle of TOC is that if a system is performing as well as it can, not more than one of its components will be. Conversely, if all parts are performing as well as they can, the system as a whole will not be (Dettmer, 1997). However, decision making focused on local impacts and performance ('cost world thinking') is common in many organisations, often driven by locally focused performance measurement regimes (Goldratt, 1997, 2006); this localised optimisation reverses the prioritisation of the global operational measurements and invariably results in both shortages of final product and Inventory surpluses at the same time (Goldratt, 2006; Goldratt & Cox, 1984)

TOC Applications

Manacapilli & Bennett (2006) note that, because military training sees classes follow a prescribed curriculum to achieve a standardised set of qualifications according to their rank and specialism, "*A technical training schoolhouse more closely resembles a factory than a university*". TOC defines a variety of applications, distilling the principles into practicable approaches for use in organisations, including for manufacturing, distribution, projects and retail sales. The manufacturing application is known as 'Drum Buffer Rope' (DBR). Essentially DBR runs production at the pace of the bottleneck (the 'Drum'), ensures the bottleneck is neither left idle nor overloaded by maintaining a 'Buffer' of queued work, and pulls new work into the system to maintain the desired Buffer level by sharing information (the 'Rope' acting as the information link) with the input controller. DBR maximises Throughput and minimises Inventory (Goldratt & Cox, 1984; Goldratt & Fox, 1986) as [illustrated](#) by Floyd (2019); this maximises the responsiveness and agility of the manufacturing process.

In real manufacturing, many different components must be produced and combined to make products, often sharing one of more resources. In this case one bottleneck will still determine Throughput (the 'red' bottleneck in Figure 2 (c)) and the assembly schedule is dictated by the availability of components from this bottleneck resource, effectively making it the Drum for the whole system (Goldratt & Fox, 1986). Goldratt, Schragenheim, & Ptak (2000) caution that improving one function of an organisation alone (i.e. manufacturing) using a TOC application without considering the consequences can cause severe unintended consequences (i.e. overwhelming distribution creating Inventory bulges that can't be turned into Throughput).

HUMAN CAPABILITY AND PERFORMANCE OF MILITARY TRAINING PIPELINES

Contemporary Human Capability challenges

In general, while all militaries need to ensure they have sufficient personnel with the right distribution of skills and abilities, smaller militaries can less afford to waste their talent as they rely to a greater degree on each person's effective contribution (Williams & Gilroy, 2006). The cost of employing military personnel is substantial: personnel costs represented 27% of 2016-17 MOD spending (UK National Audit Office, 2018). Under constant pressure to reduce costs, the UK Armed Forces have repeatedly reduced personnel numbers: notably, the 2010 Strategic Defence and Security Review (SDSR), largely driven by the 2008 financial crisis and resulting recession, cut 17,000 military personnel (around 7%) (UK Cabinet Office, 2010). As UK military personnel numbers reduced, and as threats increased in scale, diversity and complexity between the 2010 and 2015 SDSRs, the significance and criticality of the PLOD and TLOD have substantially increased.

Shortages of skilled UK Armed Forces personnel have been publicised in the media (Farmer, 2015; Mance, 2018) and through UK government reports (House of Commons Public Accounts Committee, 2018; UK National Audit Office, 2018). Around half the personnel released early under redundancy programmes to implement the 2010 SDSR personnel drawdown were from logistics, engineering and aircrew trades which now have shortfalls (UK National Audit Office, 2018). Shortages of manpower have been cited as the reason for policy changes making soldiers liable for deployment who have not fully completed their training and may not have developed all the necessary skills for their specialist roles (Bodkin, 2016). Christie et al. (2017) identified substantial challenges in scheduling RN Phase 3 training courses at times when their target audiences can attend, resulting in a proportion of personnel lacking necessary qualifications for their employment.

However, as well as skills shortages there are also some cadres with surplus personnel, predominantly at the most junior and senior levels (UK National Audit Office, 2018). In human capability terms it is crucial to have the right mix and balance of skills: for example, a surplus of chefs would not compensate for a shortage of technicians although it may mask the problem by making the total number of people employed match the total number required. In 2018 a 'Defence People Innovation Challenge' competition was offered to industry seeking 'innovative solutions' for managing UK military and civilian personnel, with five 'focus areas': Recruitment; Skills and Training; Retention; Motivation and Rehabilitation. The Recruitment area sought solutions to help "*recruit the right mix of capable, resilient and motivated people*" while in the Skills and Training area the MOD was "*particularly interested in solutions that provide approaches to more effectively deliver training outputs, reduce the time spent in training and drive efficiencies*" (UK Defence and Security Accelerator (DASA), 2018). However, the relationships and interdependencies between the five focus areas were given little emphasis.

Literature addressing Training Pipelines

Few published studies have examined the relationship between training pipelines and human capability. Like the UK Armed Forces, the US military has a base-fed personnel model. McConnell, Buchanan, Johnson, & Murdock (1983) observed that significant challenges arise in US Navy (USN) training pipelines split between multiple sites and different training providers. For example, scheduling problems and trainee backlogs can be introduced by mixing self-paced variable-duration and group-paced fixed-duration courses in the same pipeline. The actions one training provider takes to solve its trainee backlog issues can pass the backlogs on to other providers or induce new problems for them.

Scales, Okazawa, & Ormrod (2011) outline a Managed Readiness Simulator (MARS) a general purpose personnel, equipment and facilities management model developed for the Canadian Forces (CF) to forecast impacts of proposed changes to missions, personnel structures, government policies and other factors and to assist military leaders' decision making. While training can be incorporated into MARS by assigning tasks to the resources, MARS does not incorporate a comprehensive model of training pipelines. However, in 2018 the CF were reported to have shortfalls of around 2000 regular and 5,300 reserve personnel; the CF CDS blamed these shortages on personnel cuts followed by large recruiting drives which created 'bulges' that pass through the system 'like a python swallowing a meal'. The CF's intended remedy to the shortages was further and accelerated recruitment (Berthiaume, 2018). However, this may cause further travelling bulges and increase Inventory (Floyd, 2019).

Through ‘Project Air Force’ the US Air Force (USAF) commissioned a series of independent studies, via the RAND corporation, to assist development of policy on current and future employment, combat readiness, and support. Manacapilli & Bennett (2006) identified that Air Education and Training Command (AETC) lacked analytic tools to assess changes in the technical training pipeline and consequently had little capability to model its technical training process. Two simulations were developed: a model of the ‘schoolhouse’ system to develop estimates of the resource requirements for initial skills training courses (Manacapilli & Bennett, 2006) and a basic model of the AETC technical training pipeline (Harrington et al., 2017). Intended uses of the schoolhouse model included: evaluation of the change in output with changes in resourcing (facilities, instructors, and training devices); highlighting resource bottlenecks resulting from changes to the training plan; providing insight into classroom details; and assessing the change in output resulting from changes in ‘washback’ and attrition rates (Manacapilli & Bennett, 2006).

Few of the published studies of military training pipelines consider the presence or effects of bottlenecks. Manacapilli & Bennett (2006) acknowledged bottlenecks within training pipelines as a factor influencing the training capacity that can be realised. Although simple models can be used to identify primary system bottlenecks, secondary and tertiary factors were also judged significant: *“In reality, constraints are faced, and many of them are very detailed or caused by complex interaction effects with multiple parts of the training system”*. (Manacapilli & Bennett, 2006, p. 47). In a study of AETC initial technical training pipelines, Harrington et al. (2017) identified inefficiencies in three broad areas (Table 2) including inefficiencies in flow of trainees through the pipeline. However, while this study identified one commercially provided course with a high failure rate within the Cyber Systems Operator pipeline as a bottleneck, this is the only explicit acknowledgement of bottlenecks made within the study.

Table 2: Inefficiencies in USAF initial technical training pipelines (Harrington et al., 2017)

Inefficiencies in Technical Training Planning Process	Inefficiencies in Flow of Students Through the Pipeline
1. Unrealistic expectations associated with changing requirements	1. Inefficiencies associated with time not in training
2. Lack of agility in responding to changing requirements	2. Lack of realistic and consistent metrics
3. Insufficient visibility into technical training capacity	Resource Inefficiencies
4. Lack of readily available information to support execution planning	1. Improper rightsizing of the supply of instructors
5. Missing participants in the planning process	2. Inadequate resourcing of training management and instructional systems
6. Complications of guard and reserve planning	

Noting *“a lack of clearly defined, readily visible, or consistently collected metrics for how to measure efficiency in student throughput”* (p.xii) Harrington et al. (2017) observed that multiple organisations and headquarters were involved in intricate pipeline planning activities but these processes appeared to lack agility and struggled to respond to changes in demand. Participants in pipeline planning appeared reluctant to share information which impeded development of shared understanding. These observations echo Christie, Floyd and McLaughlin (2017) who identified enduring tensions, driven by divergent perspectives of efficiency and different performance measurements, between RN TRAs and TDAs within different chains of command that impeded coherent PLOD and TLOD management.

Harrington et al. (2017) noted that efficiency was sometimes considered in terms of costs, with empty seats in classes and time students spent waiting for training being equated with waste. This indicates at least some participants in training pipeline planning have a ‘cost world’ perspective. Ironically, TOC shows that filling all spaces for a non-bottleneck training module could increase the number of students waiting and the time they wait to access a later bottleneck module. At the same time, some spare capacity in the form of ‘empty seats’ is needed to be able to accommodate personnel who need to repeat training modules due to failure of have their progress delayed by factors such as injury (known as ‘washback’ in the US and ‘back class’ in the UK). Judging the capacity to set aside for washbacks using traditional pipeline management approaches is challenging: too much reduces production while not enough results in a longer waiting time before individuals trainees can recommence training (Manacapilli & Bennett, 2006).

Manacapilli et al. (2012) claim that higher washback rates increase the total training capacity needed by increasing the capacity that must be set aside for trainees retaking modules, and that this in turn incurs greater costs by increasing training time. TOC would support this claim for bottleneck modules but dispute it for a non-bottleneck module. TOC would suggest that effects on costs are better understood through analysis of the effects on Inventory: in the context of training pipelines, this is principally the total amount of trainees within the pipeline. While Inventory levels may fluctuate, the most effective way to minimise costs is to minimise the level of Inventory held within the training pipelines over time.

The studies published through Project Air Force mainly focus on initial training pipelines. Since fiscal year 2016, the gap between actual USAF maintainer staffing levels and the target levels has ‘significantly reduced’. However, shortages remain for the more experienced maintainers (5- and 7-levels) who are most consequential to the provision of human capability to meet operational needs (US Government Accountability Office, 2019).

Although the literature on training pipelines is limited and bottlenecks have very rarely been considered within the available studies, Harrington et al. (2017) argued that “*The literature on supply chain management can inform development of a system to centralize data on and improve the flow of both existing capacity and the actual flow of students through the [AETC training] system*”.

Nature and Effects of Bottlenecks

A generic and simplified representation of the flow of personnel through Phase 1, Phase 2 and Phase 3 training and into operational units (which themselves conduct tiered collective training as they generate to deploy and operate) is at Figure 3. Drawing upon the literature and analysis of the flows within the ‘base fed’ personnel model and training system, Table 3 identifies five potential types of bottleneck that can occur in training pipelines. As there are many different training pipelines operating concurrently, the bottleneck is likely to vary between different pipelines depending on the circumstances of the cadre/audience concerned. Given that human capability depends on the right mix of capable and motivated personnel with particular skills profiles, most of the bottlenecks governing most of the training pipelines will be the equivalent of the blue bottleneck in Figure 2(c) while one will act analogously to the red bottleneck in Figure 2(c) and dominate Throughput: the overall provision of human capability.

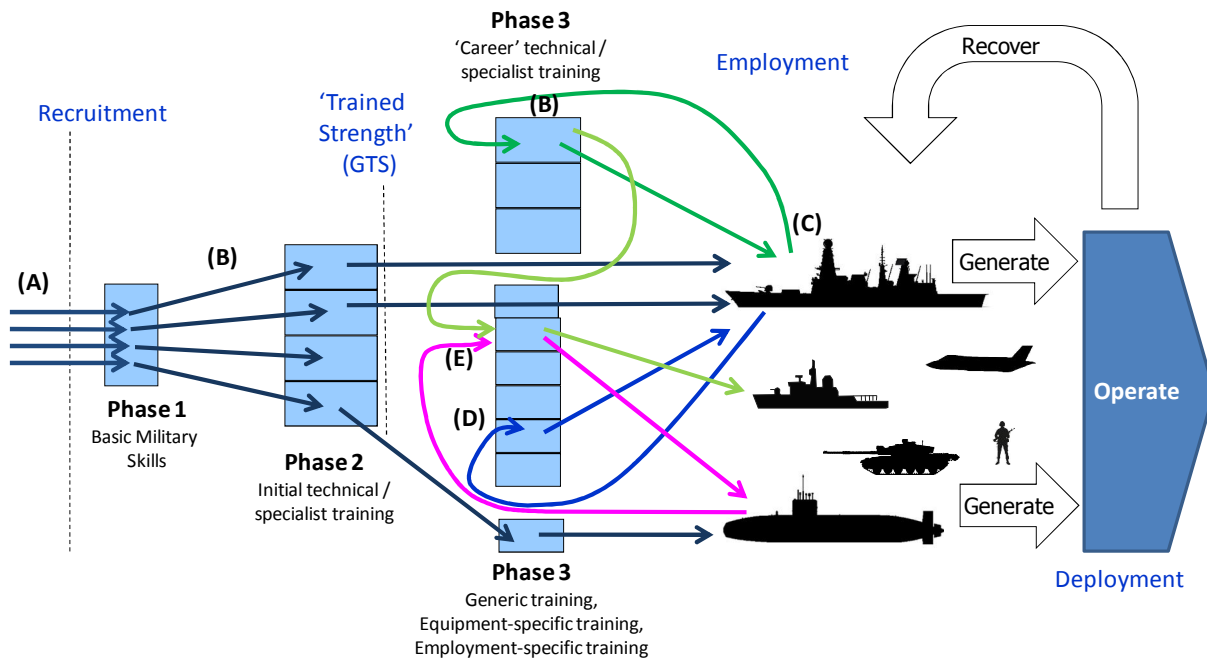


Figure 3: Flow of personnel through training pipelines

Table 3: Potential bottlenecks within military training pipelines

Fig 3	Bottleneck type	Cause(s)	Effect(s)
(A)	Inability to attract sufficient recruits to a cadre	<ol style="list-style-type: none"> 1. Scarcity of potential recruits with suitable aptitudes and/or qualifications (i.e. National skills shortages). 2. Competition from other employers. 3. Negative perceptions of the cadre/role. 4. Lack of awareness of the cadre /role among potential recruits. 	<ol style="list-style-type: none"> 1. Shortages of personnel in that cadre. (In severe cases a sustained major shortage ('black hole') can travel slowly through the rank structure).
(B)	Flow disruption within sequences of courses/modules	<ol style="list-style-type: none"> 1. Limited capacity of a key resource (often shared with other course/modules/audiences). 2. Attempted capacity matching (violates OPT Rule 1). 3. Over-recruitment (possibly to maintain Ph1 activity in reaction to type A bottleneck in other cadres). 4. 'Washback'/'Backclass' cases exceed spare capacity in following class(es). 	<ol style="list-style-type: none"> 1. Inventory build-up. 2. Cost growth. 3. Long individual wait times (which can lead to skill fade, management costs, low morale and increased outflow). 4. Lack of agility.
(C)	Demand exceeds availability of employment / workplace training capacity in units	<ol style="list-style-type: none"> 1. Competing demands placed on unit personnel and/or resources (sometimes at short notice). 2. Shortages of senior qualified and experienced personnel to supervise / train / mentor within units. 3. Over-recruitment (possibly to maintain Ph1 activity in reaction to type A bottleneck in other cadres). 4. Recruitment and/or training pipeline management not sufficiently allowing for units' employment / workplace training capacity. 5. Units' employment / workplace training capacity limited or reduced by decisions taken without regard to their role in human capability supply chains. 	<ol style="list-style-type: none"> 1. Inventory build-up. 2. Cost growth. 3. Long individual wait times (which can lead to skill fade, management costs, low morale and increased outflow). 4. Lack of agility.
(D)	Inability to reliably schedule Phase 3 training to match availability of personnel / inability to release personnel to attend when Phase 3 training is scheduled.	<ol style="list-style-type: none"> 1. Personnel arrive at units with qualification shortfalls. 2. Competing demands on unit personnel (often at short notice) including sustaining safety/security duty rosters. 3. Infrequent scheduling of some training. 4. Limited places on some training. 5. Clash with other training or leave (especially before or after deployment). 	<ol style="list-style-type: none"> 1. Qualification shortfalls. 2. Perception of 'waste' when scheduled places not filled. 3. Vicious cycle magnifying causes when training plans are 'right sized' (inevitably reduced) based on recent output.
(E)	Competition between different audiences for scarce Phase 3 course/module places.	<ol style="list-style-type: none"> 1. Factors (including vicious cycle) causing type D bottlenecks. 2. Early bulk booking of places and late/no cancellation to minimise TRAs' perceived risk. 3. Low incentive for Inter-TRA and TRA-TDA-Training Provider cooperation for best overall human capability outcomes. 	<ol style="list-style-type: none"> 1. Qualification shortfalls.

DEVELOPING GUIDING PRINCIPLES FOR TRAINING PIPELINE MANAGEMENT POLICY

For a military HR system to be effective, personnel and training strategies, policies and management practices must work together harmoniously. Training pipelines are essential to the delivery of human capability but have, to date, received relatively little attention in contemporary Defence training and personnel policy; only broad direction has

been provided along with very little guidance. Training pipeline management should therefore become much more prominent and significant in future training and personnel policy. Arguably policy covering training pipelines should be common to both training and personnel functional areas to guide and direct both consistently. HR policy should also be founded on relevant and mature theory: there is a strong argument to relate training pipeline management to Supply Chain Management principles, including TOC, to develop sound guidance and to educate practitioners. As bottlenecks dominate flow in training pipelines, policy should explicitly acknowledge the effects of bottlenecks and address how to use them to gain the maximum human capability benefits.

For a military HR system to be effective and efficient in achieving its purpose of generating and sustaining human capability it is neither possible nor desirable for all the elements of the HR system to be efficient in their own right. There must be powerful incentives for the elements, functions and teams to co-operate to provide Throughput while minimising overall Inventory and Operating Expense. Equally, incentives must discourage local optimisation. Since the way performance is measured is a key driver of behaviour in organisations (Goldratt, 2006), and the evidence suggests consistent measures of training pipeline performance are often lacking (Christie et al., 2017; Harrington et al., 2017) there is a need for common performance measures to be adopted across HR functions contributing to the provision of human capability. Such measures should be based upon the TOC global operational measurements:

- Throughput: how well does the HR system to provide the right mix of qualified people (in relation to the qualification and skills requirements of their role) to employment roles within operational units?
- Inventory: how many person-days overall are invested in training pipelines (including those not yet qualified and those waiting for a component of training to commence)?
- Operating Expense: how much money overall is spent on turning Inventory into Throughput?

Training pipeline policy should acknowledge the 5 focusing steps and incorporate guidance on how to apply them in practice. For training pipelines, this should be based on Drum Buffer Rope. For the wider HR system, it may also be necessary to consider how to ensure personnel assignments and career management is managed coherently with a Drum Buffer Rope approach to training pipeline; it is likely that the TOC distribution solution (Goldratt, 1994) would present opportunities..

RECOMMENDATIONS FOR IMPROVING THE PROVISION OF HUMAN CAPABILITY

“Stakeholders at each level maintain their own personalized spreadsheets and methods for calculating capacity. The sheer preponderance of these individual systems suggests that current data and analytics are insufficient. Every stakeholder from Headquarters Air Force to the schoolhouse managers stressed the importance of improved methodology and data sharing. [...] Each of these same stakeholders agreed there should be a more readily available answer to the question ‘What is a schoolhouse’s or AETC’s capacity?’” (Harrington et al., 2017, p. 23)

To deliver against the training pipeline management policy principles and aims proposed by this paper it is essential to be able to identify the bottleneck in any given training pipeline, and also to be able to determine the dominant bottleneck across different pipelines. This is the starting point for Drum Buffer Rope-based approaches to training pipeline management. In practice, this means powerful software tools will be needed to manage, share and analyse information, schedule training activities, model personnel flows and forecast the consequences of various scenarios.

The evidence reviewed by this paper suggests a variety of previous attempts to model military HR systems have struggled to gain sustained traction and have had limited beneficial effect. However, if the bottleneck’s capacity determines the capacity of the training pipeline and the dominant bottleneck across the pipelines determines the HR system’s capacity to provide human capability, then this provides the basis to develop the simplest model and scheduling tool with the required capability. If the bottlenecks can be scheduled at the ‘enterprise’ level by a common tool there will then be considerable latitude within which to operate the non-bottlenecks in support.

Software tools used to manage training pipelines should be based upon the same Supply Chain Management principles that should underpin policy. They should be scalable and enable sharing of the ‘single truth’ across functions and teams within the HR system. Further research should focus on development and rigorous testing of software tools for these purposes.

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