Sustainable Defence Textiles

V.A. Venkatachalam, V.A. Kaliappan and R. Vijayasekar

Abstract Business organisations need to operate sustainably for the global well-being. "Do unto the sustainability as you would have it do unto you" is the "crux", which has to vibrate in every individual's soul of Textiles and Clothing (T&C) stakeholders to ensure that "Textile world meets the needs of the present without compromising the ability of future generations to meet their own needs". This is emphasised through an overview, life cycle, sustainable/unsustainable defence T&C features, sustainable procurement practices, and twenty-first-century realities and best practices. The generic viewpoints discussed are derivable to suite defence T&C.

Keywords Defence · Sustainability · T&C · Life cycle · Procurement · Techniques · ISO · UNEP · Best practices · Standards · Labels

1 Overview on the Sustainability/Unsustainability

Business organisations have relationship to the society and environment in which they operate, and it is a vital factor in their ability to continue to operate sustainably. Sustainability means "to live a life where one is not taking any more from the earth than what one is giving back". "Sustainability is the level at which humans are able to live and co-exist indefinitely with the natural world without harming or causing damage to either side". It is a partnership with nature, a mechanism by which one is reminded to act in sustainable ways. With every scientific and technological accomplishment of today, unsustainability at varied intensities is commingled. Unsustainability phenomenon is not an absolutely unexpected state of affairs. Due to reasons of "knowingly for affluent economic gain or reasons of socioeconomic

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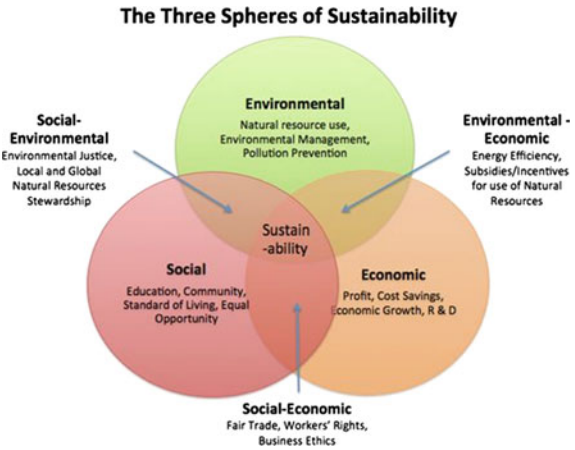


Fig. 1 Inter-relationships of three pillars of sustainability. *Source* https://www.pinterest.com/pin/442478732117449600/?from_navigate=true

coercion or inadvertently by the common people", seeding takes place as a nucleus towards a perilous setting at a later stage. Equanimity of ordinary people is being exploited in isolated situation and which adds to unsustainability at the global level. Sustainability incorporated costing to finalise the selling price is not an unpractical one. Consumers[1] are willing to spend up to 20 % more on environmental sound products and services.

Two thousand years ago, "the adversity what we face today because of environmental unsustainability" was neither known nor predictable; yet the sage Thiruvalluvar has pronounced emphatically in couplets[2] about this distressing environmental problem as stated below:

- Rains fail to fall on the land where people are unjust. When natural resources are plundered, the nature obviously feels it is no use giving such people the natural gifts
- Where there are good people, the environment is well taken care of and the Nature in return takes care of people blessing them with copious rains and plentiful crops

The sustainability is addressed with three pillars, viz. environmental, social and economic.

The interrelationships of these three pillars of sustainability and its upshot are as depicted in Fig. 1.[3]

[1] http://www.eco-officiency.com/benefits_becoming_sustainable_business.html.

[2] http://thirukkuralmadeeasy.blogspot.in/2007/01/environment.html.

[3] https://www.pinterest.com/pin/442478732117449600/?from_navigate=true.

The common principles[4] of sustainable development are as detailed in Exhibit 1:

- Conservation of biodiversity and ecological integrity
- Stable natural capital and sustainable income
- Ensuring intragenerational and intergenerational fair play
- Recognising the global aspects
- Dealing cautiously with risk, uncertainty and irreversibility
- Ensuring appropriate valuation of environmental assets
- Incorporation of environmental and economic objectives in policies and activities
- Social equity and community participation

Exhibit 1: Common principles of sustainable development

Engineering is the driving force of the industrialisation, and this needs to be sustainable to realise the quality of life. The sustainable engineering means[5] "the integration of social, environmental and economic considerations into product, process and energy system design methods". The intent is to minimise environmental impacts across the entire life cycle while simultaneously maximising the benefits to social and economic stakeholders with consideration of the complete product and process life cycle during the design exertion.

Green Economy proposed by "UNEP Green Economy Programme"—means[6]—the production, distribution and consumption of goods and services that result in improved human well-being over the long term, while not exposing future generations to "significant environmental risks and ecological scarcities" through:

- Low-carbon economy
- GDP growth subject to green conditions
- Green-collar jobs
- Circular economy
- Economy subject to ecological principles

In order to create and maintain the sustainability in the society, the four capital models as coined by the University of Melbourne—namely Human Capital, Financial Capital, Environmental Capital and Manufactured Capital, must be

[4] http://www.green-innovations.asn.au/sustblty.htm.

[5] https://www.rit.edu/programs/sustainable-engineering-ms.

[6] https://www.cbd.int/doc/meetings/im/wscbteeb-mena-01/other/wscbteeb-mena-01-unep-green-economy-arab-en.pdf.

balanced. For example, too much attention to human or manufactured capital may affect the environmental sustainability and so on with other capitals.

The declaration in Exhibit 2 is a proverb to be taken into the minds of every stakeholder concerned with the supply chain, in support of not to contribute for unsustainability.

Exhibit 2: Sustainable business model

Unsustainability elements had been set in motion as of no consequence inevitability in the early industrialisation process (as an aegis for economic development) and in the present millennium, in spite of the UN declaration "2005–2014 as the decade of sustainable development", it is by now alarmingly on track,[7] towards ecological collapse—the sixth great extinction of life on Earth—and T&C sector is one of the major subscribers to this. Unsustainability is already unleashed by the fact that "exploitation has alarmingly exceeded 1.5 times the restoring gift of nature, i.e. the nature's capability of refurbishing". CO_2 level has been increasing around 3 ppm per year, a 20-fold increase compared to pre-industrial times when the highest recorded increase was 0.15 ppm per year; 300–350 ppm of CO_2 is the threshold. These transforms are irreversible on a timescale of human civilisations.

Even if all industrial activity magically ceased today, the footprint has by now left will be felt for eons.[8] "Ecosystem services"[9] that nature performs for free include:

- Soil formation
- Water purification
- Climate regulation
- Pollination
- Nutrient cycling
- Waste treatment, etc.

[7] http://carolynbaker.net/category/collapse-of-industrial-civilization-2/.

[8] https://collapseofindustrialcivilization.com/.

[9] https://www.google.co.in/search?tbo=p&tbm=bks&q=isbn:9290907223.

Total value[10] of ecosystem services, appraised 10 years back as $33.3 trillion dollars, is twofold compared to the then world GDP, a palpable indicator on the benefit from nature every sentient being deriving without any physical and intellectual effort. "Do unto the environment as you would have it do unto you"[11] is a proverb to be recognized sincerely. Should this not be valued and reverenced every day?

The present attitude of many stakeholders is still in line with neoclassical economics as signified in Exhibit 3; each of these can contribute to environmental problems.

- *Resources are infinite or substitutable.*
- *Long-term effects are discounted.*
- *Costs and benefits are internal.*
- *Growth is good.*

Exhibit 3: Neoclassical economics

Minimum compliance as stated below is the prevalent mindset with most of the business communities unless they seriously pursue the concept of CSR, which have an influence on unsustainability:

- Follows the law, but performing not more than required.
- Accomplishing the minimum in order to not to break the law.
- Fulfilling the minimum requirement.
- Following the minimum standard.

To overcome this syndrome, practicing of Hickel's law[12] may dissuade the polluters of any kind who are prone to shatter the sustainability.

Along with the above postulates, the **dynamic concept**[13] of sustainability also needs to concurrently pulsate in the minds of everyone, especially in the views of intellectuals, who are advocating the sustainability's criticality. Societies, environments, technologies, cultures, values, aspirations change and a sustainable society must allow and sustain such change; i.e. it must allow continuous, viable and vigorous development, which is what meant as sustainable development.

[10] https://books.google.co.in/books?id=EuDGQURW6gsC&pg=PA247&lpg=PA247&dq=$33.3+Trillion+dollars&so.

[11] https://books.google.co.in/books?isbn=1895643015.

[12] http://www.counterspill.org/article/santa-barbara-oil-spill-brief-history.

[13] Hartmut Bossel, Indicators for Sustainable Development: Theory, Method, Applications, International institute for sustainable development, 1999.

2 Life Cycle

Life cycle is one of the important components for sustainability/unsustainability discussion.

Life cycle rationalism facilitates sourcing raw materials, manufacture and distribution, use, reuse, recycling, energy recovery and disposal sustainably. As voiced by PACIA,[14] it readily accelerates to:

- Recognise business value
- Identify "hot spots" for investigation
- Develop a map of supply chain
- Collate organisational and supplier information
- Have knowledge on the financial, environmental and social costs of the product over its life cycle
- Fortify relationships and collaboration with mission partners.

Life cycle design approach for resource optimisation[15] as shown in Fig. 2 starts with the fibre stage, looping their way around clockwise and ends with energy recovery.

As discussed by Fletcher,[16] the concepts: (i) negative and (ii) positive feedback loop may be an added input to contain unsustainable textiles from source to final disposal. 80 % plus of textiles environmental impact is knowable at the design stage. Sustainable design, timeless style, effective utilisation of fabric in the production process, choosing apt processing and dyeing techniques along with opportunities for recycling, resource efficiency, and design contest causing lower impact on the environment are certain strategies worth pondering. For example—Levi Strauss's[17] "Repurposed, Reimagined, Resourceful"; a lightweight, yet durable, the parachute trucker jacket-one of the pioneering attempts to reuse disposable nylon military parachutes. "Zero-waste Textile Initiative";[18] and "Turning old into new with reused sustainable fibres"[19] are some more initiatives in the direction of textile sustainability linking to life cycle.

[14] http://www.supplychainsustainability.org.au/life_cycle_thinking.

[15] http://www.georgeron.com/2014_05_01_archive.htm.

[16] RS Blackburn, Sustainable textiles—Life cycle and environmental impact, Woodhead publishing limited, 2009.

[17] http://levistrauss.com/unzipped-blog/2014/04/repurposed-reimagined-resourceful-the-parachute-trucker/.

[18] http://sfenvironment.org/news/press-release/san-francisco-launches-zero-waste-textile-initiative-to-keep-apparel-footwear-line.

[19] http://www.triplepundit.com/special/sustainable-fashion-2014/ingenious-reuse-sustainable-fibers/.

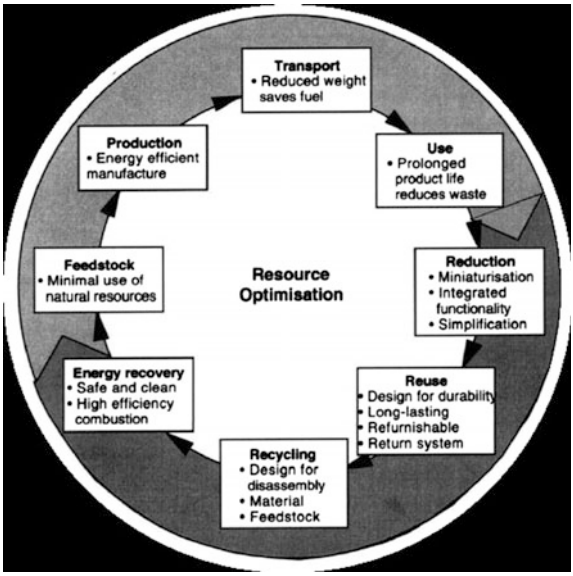
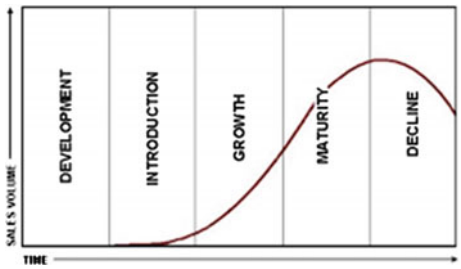


Fig. 2 Resource-optimised cradle-to-cradle life cycle concept. *Source* http://www.georgeron.com/2014_05_01_archive.htm

Unsustainability in the earlier stage of new products is because of partial ignorance due to uncertainties:

- In the conceptual model used for the design calculations,
- In the specific characteristics of the materials purchased,
- Caused by variations in processing,
- About the nature of life cycle the finished product will meet, and
- In various unsustainable unknown factors.

If all the above elements for new product/process are expected to be taken care in the early stage itself, the spirit of new developments will get hampered. These unsustainable elements can be or rather possible to put rightly as signified in Graph 1, mostly just before introduction stage, and the missed out and certain



Graph 1 Product life cycle curve. *Source* http://marketingsaffolaactivedairy.blogspot.in/2014_09_01_archive.html

unexpected unsustainable germination during the growth stages, by a systematic inclusive approach. In this context, lawmakers cannot be expected always to keep up with technological development nor would consumers necessarily want to see laws changed with each innovation. Empowerment of concerned associations and inspection agencies will facilitate continuously to ward off the unsustainability associated with every innovation and development through a balanced outlook rather than the minimum compliance on sustainability statute.

The life cycle assessment (LCA) is another important tool for achieving environment friendly products. LCA[20] is a useful tool in:

- Understanding of the important processes within the life cycle
- Identifying weak points and optimisation possibilities of analysed life cycles to further decrease the environmental impacts of the respective products
- Discover measures to effectively reduce environmental impacts
- Preventing the shifting of environmental problems to other stages in the life cycle

Many textile companies have started committing to apply LCA for their manufactured products. LCA[21] is a potentially powerful tool which can give a hand to:

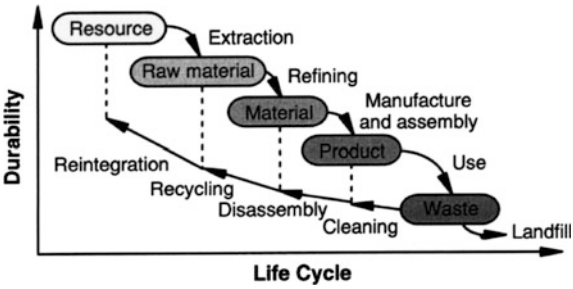
- Regulators to formulate environmental legislation
- Facilitate manufacturers to analyse their processes and improve their products
- Probably enable consumers to make more informed choices

Durability[22] of the textile product drops at each step of the product life cycle due to the impact of processing, service conditions and environmental factors as shown in Graph 2. For this reason, the durability of the military textiles is to be taken care through right approaches at each stage. The efforts underway to enhance the performance of textile materials through nanotechnology and electro-textiles may possibly add a positive value in the defence textile field.

[20] https://en.wikipedia.org/wiki/Life-cycle_assessmentISO 14040[8] and 14044[9] standards.

[21] http://www.tankonyvtar.hu/en/tartalom/tamop425/0032_kornyezetiranyitas_es_minosegbiztositas/ch11s03.html.

[22] http://www.georgeron.com/2014_05_01_archive.htm.



Graph 2 Drop in durability of textiles at each stage. *Source* http://www.georgeron.com/2014_05_01_archive.htm

3 Defence Textile Sustainability

3.1 Sustainable Textile

Sustainable textiles are that meet or exceed the environmental, social and economic performance requirements as set forth by the SMART© Sustainable Textile Standard 2.0,[23] and they have the following attributes:

- All materials and process inputs and outputs are safe for human and ecological health in all phases of the product life cycle
- All energy, material and process inputs come from renewable or recycled sources
- All materials are capable of returning safely to either natural systems or industrial systems
- All stages in the product life cycle actively support the reuse or recycling of these materials at the highest possible level of quality
- All product life cycle stages enhance social well-being

Environmental impact of textiles and garments varies significantly depending upon the type of fibre and related routes. Generally various environmental issues arise in T&C[24] are as stated in Exhibit 4.

- Energy use, greenhouse gas (GHG) emissions, nutrients releases (leading to eutrophication) and eco-toxicity from washing (water heating and detergents) and dyeing of textiles
- Energy use, resource depletion and GHG emissions from synthetic fibre manufacturing, e.g. polyester or nylon

[23] www.sustainableproducts.com/smartweb.html.

[24] Sustainability of textiles ISSUE PAPER No 11, [August 2013], Retail forum for sustainability.

Table 1 Unsustainable chemicals

Purpose	Chemicals
Detergents and auxiliaries	Nonylphenol Ethoxylates (NPEs)
Water, oil, stain and wrinkle-resistant coatings	Perfluorinated compounds (PFCs, including PFOS, PFNA and FTOH)—Formaldehyde
Fire retardant textiles	Poly-brominated diphenyl ethers (PBDEs), hexabromocyclododecane (HBCD)—Short-chain-chlorinated paraffins (SCCPs)—Asbestos
Plastic coatings	Phthalates (e.g. DEHP)—heavy metals (e.g. lead, cadmium and organotins)
Antibacterial and anti-mould agents	Silver—Triclosan—Dimethylfumarate (DMF)
Dyes and colourants	Heavy metals (e.g. mercury, cadmium and lead)—Azo-dyes

- Significant water use, toxicity from fertiliser, pesticide and herbicide use, energy use and GHG emissions associated with fertiliser generation and irrigation systems related to production of fibre crops, e.g. cotton
- Water use, toxicity, hazardous waste and effluent associated with the production stage, including pre-treatment chemicals, dyes and finishes

Exhibit 4: Environmental impact of T&C

The main GHG emissions are CO_2 from energy use, and CH_4 and N_2O from cotton production[25].

The environmental sustainability as thought-out by Multilateral Investment Guarantee Agency[26] talks about waste characteristics, pollution prevention and control, target pollution loads, treatment technologies, emission guidelines, emission levels relating to country specific legislation, monitoring and reporting.

Some of the unsustainable chemicals in use for various textile needs are as given in Table 1.[27]

The opinion by Katie Smith[28] elucidates the challenges and opportunities in T&C as below and this could be expressively accounted for defence textile needs:

[25]http://www.sifo.no/files/file78707_oppdragsrapport_1-2013_web.pdf.

[26]https://www.miga.org/documents/Textiles.pdf.

[27]http://www.unep.org/hazardoussubstances/Portals/9/CiP/CiPWorkshop2011/CiP%20textile%20case%20study%20report_21Feb2011.pdf.

[28]http://www.just-style.com/analysis/fact-fiction-and-the-future_id120417.aspx.

- The traditional cotton farming requires large quantities of water, fertilizers and pesticides; the mulesing of sheep and sericulture process is considered unethical and unsustainable.
- The viscose rayon and synthetic fibres, including polyester, polyamide and elastane, have an impact on the environment because of less sustainable resources and production process.
- Technologies such as waterless dyeing, fibre modification and solution or "dope" dyeing, as well as digital printing, have less environmental impact on textile dyeing and printing.
- The eco-friendly dyestuffs reduce water and energy usage.
- Denim finishing techniques such as bleaching and sand blasting are now getting replaced slowly by sustainable lasering and ozone processes.

Buying clothes that have been made from unsustainable means as discussed above is an approval for social and environmental exploitation, leading to unsustainability.

As an example, "Extending the average life of clothes by just three months of active use would lead to a 5–10 % reduction in each of the carbon, water and waste footprints".[29] Making from green route fibres and constructed with durability, reasonable living wages, safer factories, toxic-free, cruelty-free, etc., are considered as sustainable mode. "Greenpeace International" has prompted many T&C units to eliminate toxic chemicals from their supply chains, and chemical companies to introduce greener alternatives, a sustainable progress.

3.2 Military Textile Requirements

Right from the late twentieth century, high-performance man-made fibres well along with natural fibres having been chemically treated/coated/laminated are at task in defence and started planting its share towards unsustainability.

The primary purposes of military clothing always have been protection, functionality, and identification. "Textile learner"[30] has categorised "Features" and "Fibres" for armed forces T&C as in the Exhibits 5 and 6, respectively.

- Lightweight flame retardant clothing with buoyant property for the naval and armed forces personnel to protect them from cold—Nomex fibre
- Head hoods and hand gloves—Kevlar fibre

[29] http://www.ethicalconsumer.org/shoppingethically/ethicalfashion/eco-fashion.aspx.

[30] http://textilelearner.blogspot.in/2014/07/features-and-characteristics-of-armed.html.

- Chemically treated cotton fabrics—considered as the best
- Two ply fabrics—used for the clothing
- Blanket made for the soldiers—two ply fabric made from glass fibre
- Fibrous silica
- Ballistic fabrics for protection from shrapnel
- Flame-resistant clothing for protection from improvised explosive devices (IEDs) and other sources of heat and high energy
- Fabrics for war fighters in the event of chemical or biological attacks—multilayered fabric ensembles allow them to perform critical missions in extreme cold weather
- Moisture wicking fabrics to carry out strenuous tasks for extended periods and with more precision

Exhibit 5: Features of armed forces textiles

- Polyester
- Cotton
- High tenacity polyester
- Lycra
- Kevlar®-Para-aramid
- Coolmax®-specially engineered polyester
- Nomex®-Meta-Aramid

Exhibit 6: Fibres used for making military T&C

Along with the above, some more fibres used for certain specific defence T&C requirements are:

An array of ultra-high modules polyethylene (UHMPE) fibres for Explosive Ordnance Disposal (EOD)—characteristically gel spun polyethylene (GSPE) fibres, with trade names such as Dyneema (DSM) and Spectra aiding reduction in the weight of the garment by about 15 %.

These are also used for cut resistant gloves, helmets and other protective garments.

The aramid and Ultra-high-molecular weight polyethylene fibres facilitate excellent body armour requirements. Efforts are on in reducing the weight and bulkiness, and improving moisture management. Besides those, as heat-resistant clothing, needle felt Nomex fibre, ceramic and graphite fibre woven fabrics and silicon rubber-coated fabrics are also used.

In all the wars, T&C have played a vibrant role in providing protection to the soldiers. More than 8000 different items ranging from uniforms and body armour to tents and canteens and battle-dress uniforms (BDUs) are in use for the armed forces.[31]

T&C for military purpose faces a complex set of challenges.[32] They must provide protection, durability and comfort in a wide range of varying climatic conditions and war threats. They need to meet specific protective performance requirements[33] in battlefield tanks, aircrafts, underwater, etc., including the high risk such as gravitational forces during high acceleration–deceleration, extreme temperatures, etc. Defence forces on land, sea and air make use of woven, knitted or non-woven and all the required high-performance functionality, such as "Protection, Comfort and Practicality", have been provided through layers of materials rather than a single garment and that are characterised with:

- Protection against natural and battlefield threats
- Thermo-physiological comfort in extreme weather
- Compatibility of intra- and interclothing components.
- Low weight and bulk materials

Sigrid Tornquist[34] has pointed out that fibre reinforced, insect repellent, modular, ergonomic, chemical resistant, paper thin but super tough, omniphobic T&C is needed for defence operations. "Priorities of various requirements are determined by a number of factors, especially the threats currently being encountered and those that are anticipated in the future".

Some of the countless combat essential T&C items identified by NCTO[35] to support the Armed Forces are as in Exhibit 7.

- Combat and flight uniforms
- Helmets
- Flak jackets
- Gear for extreme weather operations
- Parachutes
- Aircraft fuel cells
- Sandbags
- Tents and shelters

[31] file:///C:/Documents%20and%20Settings/AV/My%20Documents/Downloads/nps62-050312-30%20(3).

[32] Anurag Srivastava, Defence Textiles: Present Scenario and Future Challenges, standards India, vol: 27 no. 5 & 6 12/12 August–September 2013, New Delhi.

[33] http://www.technicaltextile.net/articles/protective-clothing/detail.aspx?article_id=2605.

[34] http://advancedtextilessource.com/2014/11/u-s-army-wish-list/.

[35] http://www.ncto.org/industry-facts-figures/textiles-and-our-military/.

- Sheets
- Blankets and hospital textiles
- Airplane panels
- Ammunition bags/pouches
- Fabric for bulletproof vests/helmets
- Chemical protective suits
- Extreme weather protective fabrics
- Interfacing and lining in apparel and shoes
- Parachutes and parachute harnesses
- Personal flotation devices
- Pontoon bridges
- Rafts
- Ropes and cables
- Ship composites
- Stealth fighter plane graphite fibres
- Wet suites

Exhibit 7: Combat essential items

As revealed by Granch Berhe,[36] wide ranges of woven, coated/laminated fabrics used in defence are as given under:

- Water-repellent, waterproof, wind proof, snow shedding, cold areas clothing
- Sleeping bags with high levels of thermal insulation
- Water vapour permeable for clothing and personal equipment and tents
- Rot resistant for tents, covers, nets
- UV resistant to strong sunlight
- Air permeable to hot tropical climates
- Biodegradable discarded and buried fabrics
- Nuclear, biological and chemical protection through activated carbon
- Snow camouflage, fire resistant, moisture management, anti-odour/anti-microbial, taken care through specific fibres and chemicals as basic constituents
- Using fabrics of lightweight, low bulk, high durability and dimensional stability to manage with minimal space available, reliably in adverse conditions for long periods of time without maintenance as the specific defence needs

[36] http://www.slideshare.net/GranchBerheTseghai/7-military-textiles-52380790™.

- Multi-layer fabrics to serve diverse inevitabilities
- Combat fabrics made from non-thermoplastic fibres to minimise melt/burn injuries (extremely important)

The specific properties chartered by Arunabh Chowdhury[37] for defence applications are as detailed in Exhibit 8

- Tensile properties.
- Resistance to water and saline water.
- Resistance to chemicals.
- Camouflaging effects.
- Resistance to fire and high temperature.
- Resistance to infrared detection.
- Resistance to UV and other electromagnetic radiation.
- Resistance to ballistic impacts.
- Resistance to microbiological growth and degradation.

Exhibit 8: The specific properties for defence T&C

Requirements for advanced integrated combat clothing system[38] classified as physical, environmental and physiological are as in Exhibit 9.

Physical

- Durability to prolonged exposure to inclement weather and heavy wear
- Good tensile and tear strength and abrasion resistance

Environmental

- Water repellency, wind proof
- Battlefield (good camouflage and low-noise generation)

Physiological

- Low weight, easy to wear, minimum heat stress
- Air, moisture and vapour permeability
- Comfort and good appearance

[37]Arunabh Chowdhury, Technological Applications of Textile in Defence and Standardization Status, standards India, vol: 27 no. 5 & 6 12/12 August−September 2013 New Delhi.

[38]http://www.nitracoeprotech.org/pdf/status-report-on-protective-textiles.pdf.

Exhibit 9: Requirements for advanced integrated combat clothing system

Every single military T&C necessitates meticulous specifications and for example the parachute[39] fabric for air force to be characterised with:

- Elongation,
- Elastic recovery,
- Energy absorption,
- Porosity,
- Air permeability,
- Strength properties,
- Temperature properties,
- Ageing properties, and
- Impact loading.

Integration of some of the above functionalities through fewer layers to provide multi-layer protection crowns into reduction in life cycle costs because of few components and also effective, durable and recyclable nature. Blends such as poly-cotton and poly-viscose are sustainable, due to their specific qualities such as reduced laundering costs and enhanced fabric durability. Nanotechnology-based fabrics for camouflaging and muscles stimulation are in progress, which may also leverage the sustainability philosophy. Defence textiles characterised with certain specific features met by a range of fibres, chemicals, and technical and management processes, which for sustainability inevitabilities to be suitably regarded encompassing the pillars of sustainability and duly accounting whole life cycle. The issues, barrier to sustainability requirements, need to be addressed strategically by the defence T&C authorities. The clothing of the service personnel as such assumes greater significance when uniformity and aesthetics is looked upon, besides functional aspects. Nevertheless, while the socio-economic factors with aesthetic desire aspects influence the civilian requirements, the defence T&C is inclined more on functional and technical quality rather than on stringent cost factor. Because of this reason, military requirements such as uniforms, callisthenics clothing, extreme climate garments, back packs, sleeping bags, tents equipment covers, bags and more such products are at an advantageous status and hence could be handled in a sustainable supply chain route with less of economic constraints.

Clothing and accessories manufactured from natural and fair trade materials like soy, organic cotton, bamboo, and leather alternatives are becoming eco conscious, socially responsible, stylish and at the same time kind to our planet. This may be a meaningful choice relating to specific demanding military requirements. Most protective clothing made of inherently and permanently non-flammable aramid fibres with their ability to be recycled is viewed as sustainable. The whole product's

[39] http://lhldigital.lindahall.org/cdm/ref/collection/parachute/id/1379.

life cycle should be regarded in an integrated perspective; the defence T&C representatives from design, development, production, marketing and utilisation should work together on the eco-design of new product. As a group, they have the best chance to realise the holistic effects of the product on environmental impact.

According to the National Society of Professional Engineers, the most important ethical principle is to "hold paramount the safety, health, and welfare of the public (society)", which may be aptly extended for other sustainability pillars too. Defence textile research may adopt innovative inquest by recounting the saying by Danish Environmental Protection Agency (EPA), "for all uses and in all circumstances a suitable less toxic alternative can be found".

4 Sustainable Procurement

4.1 Sustainable Procurement—What It Means?

Sustainable procurement[40] "is not about inconveniencing the market with extra requirements; rather, it is a well-defined strategy that gradually gets into sustainable requirements in bids, supports measures and promotes dialogue and open communication between the suppliers and procurers".

The techniques suggested by Rio2016[41] for a typical context as detailed below may be mapped to match the defence-specific T&C deal.

- Substituting sulphuric acid with CO_2
- Digital textile printing
- Collection of clothing manufacturing leftovers and send to shredding machines
- Recovery of re-evaporation latent heat
- Captured heat used for drying sludge generated
- A reverse logistics programme for proper disposal of unserviceable old textiles
- Development of natural finish
- Carbon footprint optimisation
- Precautionary approach to chemicals management
- Development of supply chain policy
- Evaluation and monitoring of the supply chain

[40] https://www.ungm.org/Areas/Public/Downloads/Env_Labels_Guide.pdf.

[41] http://www.rio2016.com/sustentabilidade/wp-content/uploads/2016/02/Rio-2016-Sustainable-Textile-Guide.pdf.

ISO 20400[42]**—**The new international standard for sustainable procurement practice likely to bring value beyond the procurement by helping to disseminate CSR practices contained in ISO 26000:2010 Guidance on social responsibility, throughout supply chains, and ultimately the entire economy. The structure of the standard in line with BS 8903 is as follows:

- **Fundamentals**—the key drivers and principles of sustainable procurement
- **Policy and strategy**—key issues to consider in developing a policy and strategy
- **Organising the procurement function**—creating the organisational conditions necessary to procure sustainably and setting priorities
- **Procurement process**—alternative modus operandi for sustainable procurement

BS 8903[43] provides guidance to any size and type of organisation on adopting and embedding sustainable procurement principles and practices. It covers all stages of the procurement process which may be of interest to defence T&C.

Sustainable public procurement (SPP) includes the three pillars of sustainable development embracing transparency, fairness and non-discrimination: competition, accountability and verifiability. The SPP benefits[44] are as revealed in the Exhibit 10.

- Climate change and or greenhouse gas emission reduction;
- Ozone-depleting substances eradication
- Natural resource use optimisation
- Waste minimisation
- Job creation
- Equality and diversity
- Fair pay for supply chain workforce
- Economic regeneration
- Legal compliance
- Public image enhancement

Exhibit 10: Sustainable procurement

[42]http://www.iso.org/iso/home/news_index/news_archive/news.htm?refid=Ref1873.

[43]http://actionsustainability.itineris.co.uk/evaluate/procurement-standard.aspx.

[44]http://www.unep.org/resourceefficiency/Portals/24147/scp/procurement/docsres/ProjectInfo/UNEPImplementationGuidelines.pdf.

4.2 Sustainable Procurement Factors

Sustainable procurement is influenced as listed underneath:

(i) Policies and processes
(ii) Approaches
(iii) Key concepts
(iv) Barrier for SPP
(v) Strategies
(vi) Life cycle thinking
(vii) SPP tools
(viii) SCP indicators
(ix) Feedback loop

(i) Policies and Processes[45]

Sustainable procurement,[46] emerged from Rio Earth Summit in 1992, can be allied to defence with an outlook to maximise sustainable benefits for themselves and the whole world. This goes beyond the upfront cost, encompassing associated costs, environmental and social risks, benefits and implications. It means[47] "defence procurers meet their needs for goods, services, works and utilities in a way that achieves value for money on a whole life cycle basis in terms of generating benefits not only to them, but also to society and the economy, while minimising damage to the environment".

(ii) Approaches

There are **two approaches** as detailed below, which may be appositely considered by the defence procurers:

(i) Product-based: This is commonly used when an organisation wishes to understand the impact of a product or product range and assesses the environmental credentials for strategic and marketing purposes.
(ii) Supplier-based: Implemented effectively, this method will show whether a supplier meets the environmental standards of the organisation, along with meeting the requirements of law.

[45] http://www.gao.gov/key_issues/leading_practices_acquisition_management/issue_summary.
[46] https://en.wikipedia.org/wiki/.
[47] http://www.unep.org/resourceefficiency/Consumption/SustainableProcurement/tabid/55550/Default.aspx.

(iii) Key Concepts

- Value for money
- Environmental buying
- Supply chain assessment
- Life cycle thinking

(iv) Barrier for SPP/GPP

Economy, policy, procurement and market-related barrier for SPP/GPP in the ascending importance ascertained by UNEP[48] through a survey are as follows:

- *Difficulty in Audit office approval*
- *Protecting budding industries*
- *Concern about quality of sustainable products*
- *Lack of suppliers of SPP/GPP products*
- *Inadequate public procurement system for incorporating SPP/GPP*
- *Insufficient supply of sustainable goods and services*
- *The initial cost commitment*
- *Lack of clarity on sustainable product*
- *Budgetary/resource restrictions*
- *Lack of legislation or regulations*
- *Lack of interest and commitment from procurers*
- *Lack of technical capacities on environmental/social issues*
- *Lack of information and knowledge about SPP/GPP*
- *Perception that sustainable products are more expensive*

These barriers need forestalling through a proper system approach before realising the value of SPP.

(v) Strategies

As guided by IISD,[49] the following **strategies** may be suitably adopted for sustainable military T&C:

- By-product synergy and industrial ecology
- Cleaner production

[48] http://www.unep.org/resourceefficiency/Portals/24147/SPP_Full_Report_Dec2013_v2%20NEW%20(2).pdf.

[49] https://www.iisd.org/business/tools/bt.aspx.

- Design for environment
- Eco-efficiency
- Energy efficiency
- Environmentally conscious manufacturing
- Reduction, reuse, recycling and recovery
- Green procurement
- Performance contracting
- Pollution prevention
- Zero-emission processes

Clear, transparent and consistent policies and processes are the crux to implement strategic decisions. Engaging with suppliers who have commitment to best practice, continuous improvement and collaborative multi-supplier approaches ensure sustainability performance with a partnership.

(vi) Life Cycle Thinking[50]

As UNEP explains "it is about going beyond the traditional focus on production sites and manufacturing processes, i.e. taking into account the environmental, social and economic impact of a product over its entire life cycle, including the consumption and end of use phase". Whatever is the business size, life cycle thinking in supply chain sustainability leads to:

- Ascertain business value
- Identify "hot spots" for further investigation
- Develop the map of supply chain to one's needs
- Collate organisational and supplier information
- Understand the financial, environmental and social costs of textile and clothing over their life cycle
- Strengthen relationships and collaboration with supply chain partners
- Achieve greatest return.

Life cycle thinking facilitates all jointly being proficient from sourcing raw materials to manufacture and distribution, and from use or consumption to reuse, recycling, energy recovery and disposal.

[50] http://www.supplychainsustainability.org.au/life_cycle_thinking.

(vii) SPP Tools

A range of **tools**[51] practiced by PACIA, as given below, may be fittingly considered by the defence establishment in their T&C procurements to realise financial, environmental and social benefits:

- Life cycle map,
- Assessment matrices,
- Carbon foot printing,
- Energy mass balance,
- Life cycle costing,
- Environmental life cycle assessment, and
- Social life cycle assessment.

(viii) SCP Indicators

The **SCP indicators**[52] identified beneath are additional means to back SSP:

- Land use and biodiversity
- Socio-economic
- Waste and pollution
- Material consumption and resource use

(ix) Feedback Loop[53]

For sustainability purpose, corporations need to expand their information-monitoring systems to actively collect a broad range of ecological feedbacks in addition to social feedback.

4.3 Sustainability Reporting Initiatives[54]

A sustainability report of an organisation unfolds the economic, environmental and social impacts caused by its activities along with the organisation's values and governance model, and its commitment to a sustainable global economy. The

[51] http://www.pacia.org.au/docs_mgr/PACIA__8StepGuide_to_SupplychainSustainability.pdf.
[52] http://www.unep.org/pdf/SCP_Poverty_full_final.pdf.
[53] http://www.ecologyandsociety.org/vol2/iss2/art12/.
[54] https://www.globalreporting.org/information/sustainability-reporting/Pages/default.aspx.

sustainability reporting enables organisations to enhance their sustainable operations. The defence T&C operations may look for this initiative to ensure their sustainability requirements. The various initiatives are as elucidated in infra 9.5.2.

4.4 Sustainable Public Procurement Codes

Few codes as elucidated underneath play a positive role for SSP.

- The Sustainable Supply Chain Management SSCM[55] Code of Conduct supports positively the SPP. Sustainable supply chain management[56] and sustainability strategy[57] (embracing societal change, environmental solutions and better financial futures) and action priority[58] as recommended by Westpac is a green pasture for sustainable procurement.
- The United Nations Global Compact (UNGC),[59] an international corporate sustainability initiative, encourages the growth of responsible businesses through the adoption of ten high-level sustainability principles addressing human rights, labour standards, environment and anti-corruption.
- Green Public Procurement (GPP),[60]—Guides on environmental considerations at each stage of the procurement process towards sustainable practice from product design to disposal, which can be useful for defence T&C related stakeholders. GPP criteria aim to attain a good balance between environmental performance, cost considerations, market availability and ease of verification; defence authorities may choose, according to their needs and ambition level, to include all or only certain requirements in their tender documents.
- SMART's "Sustainable textile standard" is to help raw material suppliers, converters, manufacturers and end users, and to address the triple bottom line, throughout the supply chain. "Sustainable Textile Supply Chain Achievement Matrix"[61] guides to attain a systematic progress towards sustainability.

The above tools and advices may possibly prop up to achieve sustainability in defence T&C procurement.

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[55] http://radiorusak.esy.es/westpac-s-sustainable-supply-chain-management-code-of-conduct.pdf.

[56] https://www.westpac.com.au/about-westpac/sustainability-and-community/sustainability-action/suppliers/sustainable-supply-chain/.

[57] https://www.westpac.com.au/docs/pdf/aw/SSCM_Framework.pdf.

[58] https://www.westpac.com.au/docs/pdf/aw/SSCM_CodeofConduct.pdf.

[59] https://en.wikipedia.org/wiki/United_Nations_Global_Compact.

[60] http://ec.europa.eu/environment/gpp/eu_gpp_criteria_en.htm.

[61] SMART© Sustainable Textile Standard 2.0—sts-v2.

4.5 Sustainability Certifications

The following sustainability certifications may be considered as reinforcement in the defence T&C procurement process:

- **Global Reporting Initiative (GRI)**[62]—An international-independent organisation that helps businesses, governments and other organisations understands and communicates the impact of business on critical sustainability issues such as climate change, human rights, corruption and many others.
- **Higg Index**,[63] from Sustainable Apparel Coalition (SAC)—A sustainability measurement tool for apparel companies to measure the impacts of their products across the value chain—single approach for measuring sustainability for all buyers without investing in multiple sustainability technologies and certification processes. It is a holistic self-assessment tool empowers brands, retailers and facilities of all sizes, in their sustainability journey, to measure their environmental and social and labour impacts and identify areas for improvement.
- **OEKO-TEX**[64]—focuses on harmful chemicals; specific certifications include "OEKOTEX 100 Standard" and Sustainable Textile Production (STeP)[65]—A certification system to recognise brands, retail companies and manufacturers within the textile chain to communicate their path to sustainable production to the public in a transparent and credible manner.
- **Global Organic Textile Standard (GOTS)**[66] A worldwide standard for processing organic fibres. It uses ecological and social criteria that cover the entire textile supply chain.
- **Bluesign**[67]—brings to light resource efficiency, emissions to air and water, and consumer health and safety; applicable to brands and manufacturers, as well as chemical suppliers—but earmarked towards larger industry players.
- **Better Cotton Initiative (BCI)**[68]**—**promotes and maintains a set of holistic standards for the cotton supply chain, covering environmental, social and economic sustainability.
- **Cradle-to-Cradle (C2C) Certified**[69]—guides product designers and manufacturers towards creating products that use safe and reusable

[62] https://www.globalreporting.org/resourcelibrary/2012-2013-Sustainability-Report.pdf.
[63] http://apparelcoalition.org/the-higg-index/.
[64] https://www.oekoNtex.com/en/manufacturers/manufacturers.xhtml.
[65] http://www.testex.com/en/downloads/STeP_by_Oeko-Tex/en/STeP-FAQ_en.pdf.
[66] http://www.global-standard.org/the-standard.html.
[67] http://www.bluesign.com/industry.
[68] http://bettercotton.org/aboutNbetterNcotton/betterNcottonNstandardNsystem/.
[69] http://www.c2ccertified.org.

materials, use clean and renewable energy, protect water supplies, and advance social and environmental justice.

5 T&C Sustainability in Twenty-First Century

In conceptual age, i.e. in the twenty-first century the sustainability is at perilous phase because of continued unmindful industrial activity-lacking concern for sustainable pillars. Inter alia, the following techniques, in which some are in vogue in other engineering fields for their sustainability, may be tried in support of sustainable twenty-first-century defence T&C requirements:

1. Clean by design
2. Global reporting initiative
3. Standards and labels
4. Eco-labels
5. Quality function deployment (QFD)
6. Operational research (OR)
7. Cost-benefit analysis
8. Lean manufacturing

5.1 Clean by Design[70]

As said by NRDC,[71] manufacturing practices in some countries and in a number of industries are generally less efficient, using more energy, water and materials than

[70] http://www.ecouterre.com/nrdcs-clean-by-design-helps-chinas-garment-industry-turn-a-corner/.
[71] https://www.nrdc.org/resources/clean-design-apparel-manufacturing-and-pollution.

necessary. Even marginal improvements in manufacturing are expected to deliver admirable cost savings in energy, water and chemical usage, leading to improved sustainability. It motivates to improve process efficiency and to reduce waste and emissions aiding for sustainable environment. Informed decisions as recognised from ethical theory in four impact areas, namely Raw Materials, Manufacturing, Transportation and Consumer Care, facilitate to reduce unsustainable footprint. The eight potential starting points as in Exhibit 11 are capable of increasing profitability at the same time advances sustainable textile manufacturing.

(i) Undertaking failure analysis when things go wrong
(ii) Standardising optimal methods and recipes
(iii) Substituting enzymes in pre-treatments
(iv) Investigating opportunities to reduce salt in dyeing recipes
(v) Increasing reliance on higher fixation dyes
(vi) Improving machine utilisation
(vii) Scheduling optimally to minimise cleaning in between each batch of processing
(viii) Monitoring continuously to check whether implementation of improvements is in place

Exhibit 11: Promising starting points

Cleaner Production (CP)[72] as suggested by Rio 2016 facilitates the realisation of:

- Waste elimination
- Minimisation or elimination of raw materials and other inputs impacting the environment
- Increased energy efficiency
- Reduction or elimination of waste and emissions
- Reduction of pollution
- Reduction in costs of waste management
- Minimisation in environmental liabilities
- Increased health and safety
- Development in environmentally friendly products
- Enhancement in company's image
- Increase in productivity

[72] http://www.rio2016.com/sustentabilidade/wp-content/uploads/2016/02/Rio-2016-Sustainable-Textile-Guide.pdf.

Techniques professed by Oregon, Department of Environmental Quality,[73] also avoid, eliminate or reduce the creation of pollutants at the source. The benefits to business are:

- Reduced operating costs
- Reduced compliance costs
- Reduced liability
- Increased productivity
- Increased marketability as a "green" business
- Even possibly increased profits

5.2 *Sustainability Reporting Initiatives*

Major sustainability reporting guidance[74] includes:

(i) Global Reporting Initiatives (GRI's Sustainability Reporting Standards)
(ii) The Organisation for Economic Co-operation and Development (OECD guidelines for Multinational Enterprises)
(iii) The United Nations Global Compact(UNGP)
(iv) ISO 26000, International Standard for social responsibility

(i) Global Reporting Initiative[75]

A sustainability report measuring, disclosing and accountable to internal and external stakeholders aimed at organisational performance in the direction of sustainable development. The GRI Guidelines are intended to be applicable to organisations of all sizes and types operating in any sector. However, they were developed primarily with the needs of larger businesses in mind.

[73] http://www.deq.state.or.us/programs/sustainability/10ways-businesses.htm.
[74] https://www.globalreporting.org/Information/about-gri/Pages/default.aspx.
[75] Sustainability Reporting Guidelines, © 2000–2006 Global Reporting Initiative, Version 3.0.

(ii) OECD[76]

OECD Guidelines for Multinational Enterprises are far-reaching recommendations for responsible business conduct. It says, "Inspiring the suppliers may be a step forward in the direction of sustainability" and the practices are as indicated under:

- Mapping the impacts and set priorities, and selecting useful performance indicators
- Measuring the inputs used in production, assessing operations of the facility and evaluating products
- Understanding measured results and improving performance

(iii) The United Nations Global Compact[77]

The United Nations Global Compact is a United Nations initiative to encourage businesses worldwide to adopt sustainable and socially responsible policies, and to report on their implementation. It is a principle-based framework for businesses, stating ten principles in the areas of human rights, labour, the environment and anti-corruption.

(iv) ISO 26000[78]

ISO 26000 provides guidance on how businesses and organisations can operate in a socially responsible way. This means acting in an ethical and transparent way that contributes to the health and welfare of society.

(a) Eco-functional Index[79]

Eco-functional Index proposed by Subramanian Senthilkannan Muthu et al., encompassing functional and ecological properties combined with consumer behaviour and covering inputs (raw materials, process of manufacture, functional properties and ecological properties) and outputs (quality, functionality, 3R s, human impact and environmental impact), would be serving the interest of designers, manufacturers and downstream players.

[76] http://www.oecd.org/innovation/green/toolkit/actionstepsforsustainablemanufacturing.htm.

[77] https://en.wikipedia.org/wiki/United_Nations_Global_Compact.

[78] http://www.iso.org/iso/home/standards/iso26000.htm.

[79] http://www.sciencedirect.com/science/article/pii/S1470160X1200369X.

5.3 Standards and Labels

5.3.1 Standards

ISO 14000 family[80] of standards comprising the following categories acts as practical tools for to manage sustainable responsibilities:

- Environmental Management Systems (ISO 14001)
- Environmental Auditing (ISO 14010, 14011, 14012)
- Environmental Labelling (ISO 14024)
- Environmental Performance Evaluation (ISO 14031)
- Life Cycle Assessment (ISO 14040)

ISO 14000[81] standards ensuring sustainable development and addressing triple bottom line comprise:

- *Environmental management systems (EMS)*,
- *Auditing standard, environmental performance*,
- *Environmental labels and declarations*,
- *Life cycle assessment (LCA)*,
- *Greenhouse gas (GHG) accounting and verification*,
- *Environmental communication*,
- *Environmental aspects in product standards*,
- *Eco-efficiency assessment, Material flow cost accounting (MFCA)*,
- *Carbon footprint of products*,
- *Eco-design, and*
- *Quantitative environmental information*.

These tools lead to:

- *Reduced raw material/resource use*,
- *Reduced energy consumption*,
- *Improved process efficiency*,
- *Reduced waste generation and disposal costs, and*
- *Utilisation of recoverable resources*.

[80] http://www.iso.org/iso/iso14000.

[81] www.iso.org/managementstandards.

ISO 14001, the Environmental management system (EMS) requires companies to commit to pollution prevention and continual improvement as part of the usual cycle of business management, which is an en route for sustainability.

ISO 14044:2006, Environmental management—life cycle assessment—requirements and guidelines is designed for the preparation, conduct and critical review of life cycle inventory analysis.

The main benefits of implementing an EMS and subsequent certification of the system are:

- Improved internal organisation with clear responsibilities,
- Compliance with environmental expectations of customers,
- Access to new markets,
- Good relationship with the community,
- Waste minimisation,
- Materials and energy conservation,
- Process improvement/increase in productivity,
- Better environmental performance.

ISO 26000:2010[82]—Guidance on social responsibility, which is already being followed by some MNCs,[83] contributes to sustainable development. It encourages industries to go beyond legal compliance and an essential part of social responsibility. It promotes common understanding in the field of social responsibility and complements other instruments and initiatives. This along with "United Nations Global Compact's" ten (see footnote 83) universally accepted principles such as human rights, labour, environment, anti-corruption initiative are excellent guidelines to realise sustainability requirements for defence T&C.

The ISO 14000 family, which comprises a number of standards, complements ISO 14001-2015 and with ISO 9001, SA 8000, OHSAS 18001, REACH, etc., may be considered as added twenty-first-century tools for sustainable T&C management.

ISO 14001:2015 the environmental management system—T&C organisations get benefitted. ISO 9001 Certification provides the foundation for better customer satisfaction, staff motivation and continual improvement. 2015 version of ISO 9001[84] Standard focuses on documentation of implementation of processes and as evidence that activities were performed. It includes three basic core concepts:

[82] http://www.iso.org/iso/catalogue_detail?csnumber=42546.

[83] http://www.iso.org/iso/home/news_index/news_archive/news.htm?refid=Ref1997.

[84] http://www.ursindia.com/iso_9001/hosur/textile%20and%20textile%20products.aspx.

(a) *Process approach*
(b) *Plan-do-check act—methodology*
(c) *Risk-based thinking*

SA8000 is an auditable certification standard that encourages organisations to develop, maintain and apply socially acceptable practices in the workplace. OHSAS 18001[85] is an Occupation Health and Safety Assessment Series for health and safety management systems. It is intended to help an organisation to control occupational health and safety risks. REACH[86] shifts the onus from public authorities to industry with regard to assessing and managing the risks posed by chemicals and providing appropriate safety information for their users.

5.4 ISO Environmental Labels

Environmental labels are aimed at progressive sustainable patterns of production and consumption. The textile sustainability labels help to make the production sustainable coupling with increase in efficiency and profitability of the manufacturers. There are companies that have already started marking green products and include some environmental indicators such as life cycle assessment, water footprint, CO_2 emissions pertaining to their products manufactured, in their website or product labelling. They inform their consumers about their manufacturing process.[87]

The ISO has categorised[88] environmental labels as Type I, Type II and Type III.

Type I: Awards license that authorises the use of environmental labels on products indicating overall environmental advantages of a product within a particular product category, based on life cycle considerations.
Type II: Informative environmental self-declaration claims—refers to an environmental aspect of a product, to a component of the product or to its packaging.
Type III: Voluntary programs that provide quantified environmental data for a product under pre-set categories of parameters are defined by a qualified third party, based on a life cycle assessment, and verified by that or another qualified third party.

[85] http://www.ohsas-18001-occupational-health-and-safety.com/what.htm.
[86] http://ec.europa.eu/growth/sectors/chemicals/reach/.
[87] https://www.diva-portal.org/smash/get/diva2:704976/FULLTEXT01.pdf.
[88] http://www.sustainabilitydictionary.com/eco-labels/.

5.5 Eco-labels

Eco-labels—a subgroup[89] of environmental labels focuses on all aspects of the "life" of a product, from design, production, operation and maintenance to disposal. An eco-label is "a visual communication tool indicating environmentally preferable products, services or companies that are based on standards or criteria".[90] And of the 309 eco-labels identified worldwide, 41 cover textiles.[91] UNEP has categorised[92] the eco-labels with implementation Guidelines.

5.6 Sustainability and Quality Function Deployment (QFD)

Quality function deployment (QFD)[93] is a widely used TQM tool for translating the Voice of Customer (VOC) into such as technical and sustainability components. The main bottom line of the QFD approach is how to construct the house of quality (HoQ) including how to identify the correlation between the customer needs including sustainability aspects (normally called Whats) and the engineering characteristics (normally called Hows). The development of HoQ would involve cross-functional team or members from different departments in industry.

A typical generic HoQ is depicted as in Fig. 3, in which, well along with other criteria, T&C sustainability-specific factors can be posted to get the optimum benefit.

The relationships and correlations are as portrayed in Fig. 4 and this exercise is capable of addressing the sustainability needs related to development of T&C, utilisation of resources and up to sustainable disposal. Figure 5 is an illustration of HoQ profile to incorporate sustainability requirements.

5.7 Operational Research (OR) and Sustainability[94]

Operational research addresses problems in the sustainability domain such as energy and water usage efficiency, scarce resource management, reverse, recycling,

[89] https://www.ungm.org/Areas/Public/Downloads/Env_Labels_Guide.pdf.

[90] http://www.keystone.org/spp/environment/Green-Products-Roundtable.

[91] http://www.fibre2fashion.com/industry-article/5388/creating-a-global-vision-for-sustainable-textiles?page=1#.

[92] http://www.unep.org/10yfp/Portals/50150/10YFP%20SPP/UNEPImplementationGuidelines.pdf.

[93] http://www.ijmmm.org/papers/017-E108.pdf.

[94] http://www.journals.elsevier.com/european-journal-of-operational-research/call-for-papers/call-for-papers-trends-in-operation.

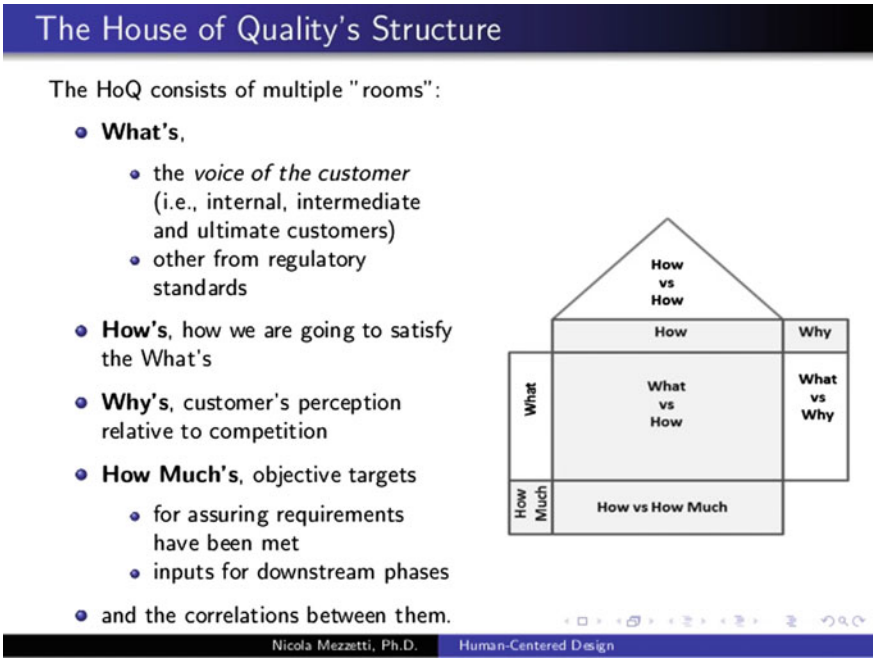

Fig. 3 Generic HoQ. *Source* http://www.ijmmm.org/papers/017−E108.pdf

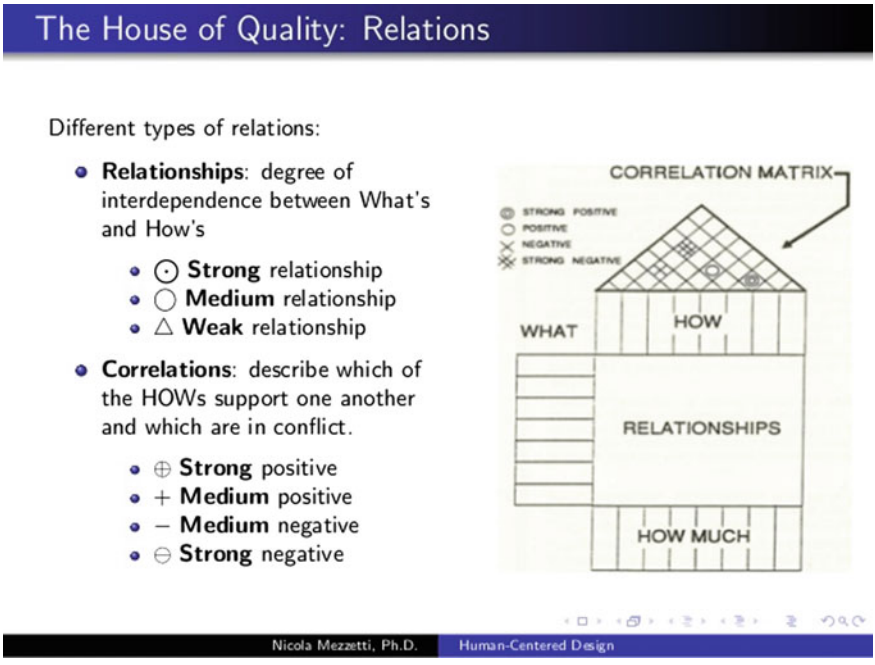

Fig. 4 HoQ relationships and correlations. *Source* http://www.slideshare.net/nicolamezzetti/humancentered-design-customer-focus-requirements-engineering

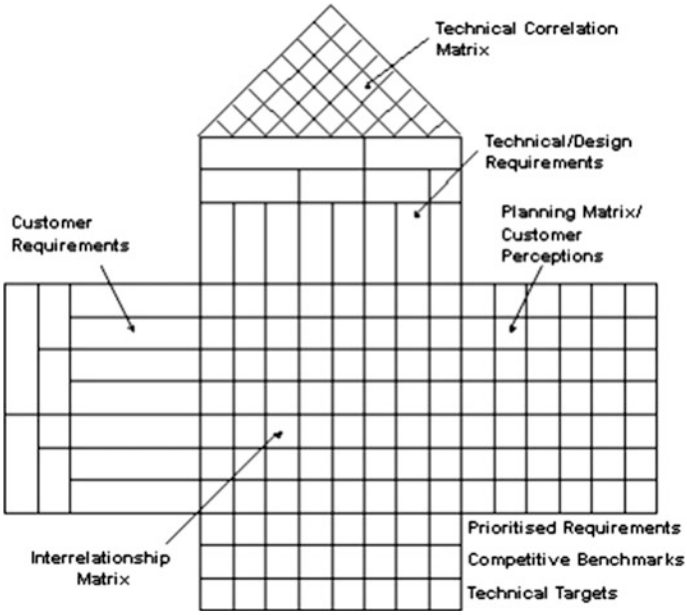

Fig. 5 HoQ profile to place sustainability requirements. *Source* https://blog.cognizantzdlc.com/category/automated-lifecycle-engineering/page/2/

remanufacturing and waste management, reducing carbon emissions, disaster management and emerging problems such as migration crisis management. For scheduling, vehicle routing, facility location, supply chain design, warehouse management, capacity expansion and production planning problems, OR will show the way to an effective T&C-specific sustainable management.

5.8 Cost-Benefit Analysis and Sustainability

Cost-Benefit Analysis (CBA) Approach: In this utilitarianism approach, the objective is not to achieve a completely clean environment, but rather to achieve an economically beneficial level of pollution with human health and environmental considerations. If T&C stakeholders do not take this in their mind and if individual company does not practice this, it will only force to resort into **Cost-Oblivious Approach (COA)**. In COA, cost not taken into account; only the acceptable level of environmental degradation is criterion—such as in the rights and duty ethics. Not practicable, especially in T&C where resources are not infinite and that will be the end of industrialised textile civilisation.

5.9 *Lean*[95] *and Sustainability*

Lean manufacturing is derived principally from the Toyota Production System (TPS). Lean emphasises efficiency, reducing cost and time, and action. It benefits operational, administrative and strategic improvements. It is a systematic method for the elimination of waste created through "overburden" and "unevenness in workloads" (enemies of sustainability) within a manufacturing system.

Waste as shown in Fig. 6 principally does not need to exist. Lean helps the environment without really intending to—in a sense, more efficient production means, less energy, less material, less pollution to air and water, and less hazardous solid waste—which leads to eliminating pollution at the source rather than costly "end of pipe" controls. As waste is eliminated, quality improves while production time and cost are reduced, aiding to sustainability. It is a matter of rethinking to find new uses for the waste material.

Lean is a set of "tools"[96] that give support for identification and steady elimination of waste. The number and type of tool depends on the type of product and production system. A non-exhaustive list of lean tools would include:

SMED—a rapid and efficient way for converting a manufacturing process from the current product to running the next product.

Value stream mapping—a method for identifying the inherent waste and losses within an operation analyse and design the flow of materials and information required.

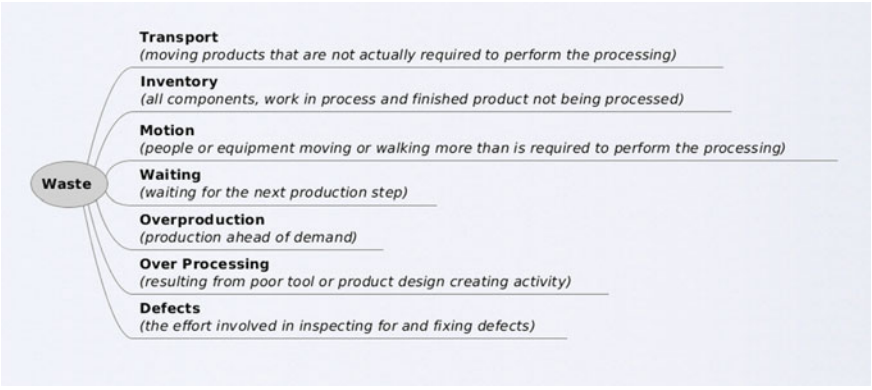

Fig. 6 Types of waste. *Source* https://en.wikipedia.org/wiki/Muda_(Japanese_term)#/media/File:Different_kinds_of_waste_in_lean_manufacturing.png

[95] https://www.greenbiz.com/news/2007/03/26/lean-manufacturing-environment-and-bottom-line.

[96] https://en.wikipedia.org/wiki/Lean_manufacturing.

6S—is well-known 5S plus the added step of safety.

Kanban—it is a visual signal to trigger an action as a layer on top of existing process towards gradual benefit.

Poka-yoke—error-proofing:

- Abnormality detection
- Stopping
- Correcting the immediate condition
- Root cause Investigation and installing countermeasure.

Total productive maintenance—elimination of time batching and mixed model processing.

Rank-order clustering—Grouping machines logically so that material handling can be minimised.

Single point scheduling[97]—This gives a real-time overview of customer's demand and to plan in advance, so that one can fulfil the requirements reliably and efficiently, while keeping finished stock inventories as low as possible.

KAIZEN[98]—All the stakeholders are given insights into the company's intentions, and they can warn the management if the stated sustainable targets have not been reached. As it is a continuous improvement, it is a good methodology to realise sustainability progressively.

The following steps ought to be implemented to create an ideal lean manufacturing:

- Design a simple manufacturing system
- Recognise that there is always room for improvement
- Continuously improve the lean manufacturing system design

All the above, lean tools may be utilised aptly based on the resource, process, product, utility and organisation nature linking to defence T&C needs and sustainability requirements.

5.10 Developments in T&C Front

The developments taking place in T&C front are most likely to be helpful for sustainability as discussed in the following paragraphs:

[97] http://www.industryweek.com/companies-amp-executives/lean-enterprise-goes-large.

[98] http://www.csrwire.com/csrlive/commentary_detail/2853-Kaizen-and-the-Art-of-Sustainability.

As communicated by Christer Wretfors Bengt Svennerstedt,[99] **Bio-fibres**, CO_2 neutral (when burned), from renewable materials tested for military purpose are most likely to become an important sustainable source in the conceptual age. With the emergence of nanotechnologies, textiles are benefitting a lot and the military textiles by the way of longer reliable performance will sure to become more sustainable.

Paul Anastas[100] has postulated twelve principles of **green chemistry**, which can be supportive to sustainable defence textile manufacturing. While environmental chemistry focuses on the effects of polluting chemicals on nature, green chemistry focuses on technological approaches to prevent pollution and reduce consumption of non-renewable resources.

As pointed out by Ingun Grimstad Klepp.[101] "**Better Mill Initiative**" is to develop tailor-made support to textile dyeing and finishing mills sustainability. "Zero-waste concepts", a thought, may conceivably contribute to the exertions taken towards sustainability. The effluent treatment processes such as biological treatment, coagulation-flocculation treatments (CFT), adsorption on activated carbon, ozone treatment, electrochemical technique, reverse osmosis, nano-filtration, and ultra-filtration used alone or combining (sometime as no process alone is efficient enough to treat the textile effluent and hence combination of one or two processes may be more effective) are expected to facilitate this inventiveness.

As proposed by "Natural Step"[102] **Sustainability Life Cycle Assessment (SLCA)** approach facilitates to define, assess and communicate product sustainability and provides a strategic outline on the social and ecological sustainability at the product level.

Life cycle mapping, assessment matrices, carbon foot printing, life cycle costing, energy mass balance, life cycle assessment, environmental life cycle assessment and social life cycle assessment as put forth by **PACIA**[103] as "**life cycle tool**" are apposite (for both new and experienced professionals) for sustainable approach.

As promoted by **SMART** criteria, "Sustainable Textile Standard"[104] is intended to allow inclusive participation and encourage the progressive drive of the textile industry towards sustainability. This standard identifies six levels of sustainable attribute performance and four levels of achievement by which textile materials and products can be measured with respect to specific attributes that link progress towards sustainability. "Sustainable Textile Supply Chain Achievement Matrix" covers all textile product stages: raw materials, transportation, manufacturing, use and final disposition. By using this standard, defence T&C supply chain

[99] http://allan.jbt.slu.se/publikationer/rapport/Rapport-142.pdf.

[100] https://en.wikipedia.org/wiki/Green_chemistry.

[101] http://norden.diva-portal.org/smash/get/diva2:840812/FULLTEXT01.pdf.

[102] http://www.thenaturalstep.org/our-work/slca/.

[103] http://supplychainsustainability.org.au/life_cycle_thinking/life_cycle_tools.

[104] https://www.google.co.in/?gfe_rd=cr&ei=ZjAbV6rtKcyo8wfJt7zQBA&gws_rd=ssl#q=SMART+criteria%2C+%E2%80%9CSustainable+Textile+Standard%E2%80%9D+.

stakeholders will be able to expressively and continuously improve their sustainable performance.

The benefits are:

- Design innovation by attentive contemplation of materials and resources
- Value added materials and products designed for safe reclamation and reuse
- Ecological restoration
- Long-term-reinforced customer relationships by offering forward-looking solutions to environmental problems
- A shared environmental programme serving local communities
- Reduced liability and need for regulation
- Compatibility with other market trends
- Government procurement and growing consumer demand for sustainable products.

As detailed by Jenna,[105] the reuse of polyester garments uses merely 1.8 % of the energy required for manufacture of these goods from virgin materials and the reuse of cotton clothing uses barely 2.6 % of the energy required to manufacture those from virgin materials.
Anne C. Wooldridge et al.,[106] says that taking into account extraction of resources, manufacture of materials, electricity generation, clothing collection, processing and distribution and final disposal of wastes, for every kilogram of virgin cotton displaced by second-hand clothing, approximately 65 kWh is saved, and for every kilogram of polyester, around 90 kWh is saved, hence to the advantage of economic and environmental sustainability.
As Ram Nidumolu et al.,[107] put forth that sustainability is mother layer of organisational and technological innovations that benefits both bottom line and top line by the way of reducing the inputs they use and generating additional revenues from sustainable products enabling companies to create new businesses.
Smart companies treat sustainability as innovation's new avant-garde. Derived from this, "Innovating sustainability"[108] means making intentional changes to

[105]Watson http://www.treehugger.com/style/974-net-energy-savings-from-reusing-cotton-clothing-lca-the-salvation-army.html.

[106]http://www.ecpar.org/sites/ecpar.org/files/documents/Wooldridge_LifeCycleAssessment.pdf.

[107]Nidumolu, R., Prahalad, C.K., &Rangaswami, M.R. 2009. Why sustainability is now a key driver of innovation. Harvard Business Review, 87(9): 57–64.

[108]http://nbs.net/wp-content/uploads/NBS-Executive-Report-Innovation.pdf.

organisational products or processes that produce environmental and/or social benefits as well as economic value and it has coined three paradigms:

(i) "Eco-Efficiency"—"Doing the same things better"
(ii) "New Market Opportunities"—"Doing good by doing new things"
(iii) "Societal Change" "Doing good by doing new things with others"

These three approaches are constituted as detailed below:

Eco-Efficiency—"Doing the same things better":

- Organisation level
- Product level
- Service level

New Market Opportunities—"Doing good by doing new things":

- Disruptive new products that change consumption habits
- Disruptive new products that benefit people
- Replacing products with services
- Replacing physical services with electronic services
- Services with social benefits

Societal Change—"Doing Good by Doing New Things with Others":

- Industrial symbiosis with the concept of "circular economy"

Sustainable design[109]—although the practical application varies among disciplines, some common philosophies such as low-impact materials, energy efficiency, emotionally durable, reusable, recyclable, material from renewable sources are expected to be futuristic thinking.
As cited by Thomas Bieker,[110] "Sustainability Balanced Score card (SBSC)" translates sustainability visions and strategies into action. It displays how intangible assets may contribute to the sustainability of companies. The SBSC initiates the integration of sustainable aspects and objectives into the core management.

[109] https://en.wikipedia.org/wiki/Sustainable_design.
[110] http://citeseerx.ist.psu.edu/viewdoc/download?rep=rep1&type=pdf&doi=10.1.1.200.9541.

The emerging three-dimensional printing, which uses ultraviolet beams to fuse layers of powdered, recyclable thermoplastic into shape, leaves behind virtually no waste. Its localised production and one-size-fits-all approach necessitates less labour and compresses fabrication.[111] A new bio-based nylon fibre with in-built moisture absorption and flame retardancy properties derived from renewable sources is being tested by the Chinese military to replace existing polyester-based fabrics likely to scale up the sustainability production.[112]
In a waterborne technology,[113] the PU is delivered and processed without solvents and provides a safer working environment; less pollution; and high efficiency, as textiles can be processed with 95 % less water and 50 % less energy compared with conventional technologies. A base layer of the coating is created from this.
Wal-Mart's[114] "three environmental goals" as signified below lead to immediate and far-reaching sustainability:

- To be supplied 100 per cent by renewable energy.
- To create zero waste.
- To sell products that sustain our resources and environment.

DyeCoo[115] sustainable route of waterless dyeing and supercritical CO_2 ($scCO_2$) textile processing technology is in offing to the benefit of textile processors.
"Closed loop" or "circular textiles",[116] in which new clothes are made from existing clothing and textiles, being practiced may have positive effect on sustainability.
The synthetic spider silk,[117] a forthcoming resource, can become a biodegradable soldier's protection for the conceptual era.

6 Best Practices

The best practices as elucidated beneath are ways forward to realise best sustainable defence T&C business practices.

[111] http://www.ecouterre.com/are-3d-printed-fabrics-the-future-of-sustainable-textiles/.
[112] Dornbirn, Chinese military backs bio−based nylon developments; Ecotextile News September 2015.
[113] http://www.technical-textiles.net/terms/coating-and-laminating-3.
[114] https://www.greenbiz.com/article/walmart-sustainability-10-birth-notion.
[115] http://www.huntsman.com/corporate/a/Innovation/DyeCoo%20delivers%20sustainable%20textiles.
[116] http://www.theguardian.com/sustainable-business/2014/sep/24/closed-loop–textile-recycling-technology-innovation.
[117] Moon parka, TechTex India, Jan−Mar 2016, vol. 10, issue 1.

NRDC[118] suggests ten best practices, viz., four water-saving best practices, five energy (Fuel)-saving best practices and one electricity-saving best practice.
DyeCoo's CO_2 technology,[119] 100 % water-free process and chemical-free solution with a lean and clean outlook being practiced by "Major Brands" is a major step forward in sustainable textile processing.
DryDye,[120] a breakthrough sustainable technology that altogether eliminates the need for water in the dyeing process uses 50 % less energy and 50 % fewer chemicals than traditional dyeing methods.
The ten pragmatic best practices for T&C industries sustainability practices according to Linda Greer et al.[121] are:

- Leak detection, preventive maintenance and improved cleaning
- Reuse cooling water
- Reuse condensate
- Reuse process water
- Recover heat from hot rinse water
- Pre-screen coal
- Maintain steam traps
- Insulate pipes, valves and flanges
- Recover heat from smokestacks and
- Optimise compressed air system

Defence authorities can take-up these measures for military T&C in support of sustainability;

As referred by Thomas Bieker,[122] "Sustainability Balanced Score card" concept offers an opportunity to translate sustainability visions and strategies into action. It demonstrates how intangible assets may contribute to the sustainability of companies. The SBSC provides high potential for the integration of environmental and social aspects and objectives into the core management.
Kelli and Sean Donovan suggest[123] that if entire industry teams together—that is from growers, manufacturers, designers, retailers, consumers, etc., T&C can make a transformation towards ethical and sustainable products.
Technology development in near future may result to freshen clothes without washing, efficient sorting of used clothing, new fibre recycling technology and new

[118] https://www.nrdc.org/sites/default/files/rsifullguide.pdf.
[119] http://www.dyecoo.com/dyecoo/.
[120] http://www.dyecoo.com/adidas-applies-drydye-technology-to-its-prime-t-range/.
[121] https://www.nrdc.org/sites/default/files/rsifullguide.pdf.
[122] http://citeseerx.ist.psu.edu/viewdoc/download?rep=rep1&type=pdf&doi=10.1.1.200.9541.
[123] http://www.ifm.eng.cam.ac.uk/uploads/Resources/Other_Reports/UK_textiles.pdf.

low-temperature detergents as a means to sustainability. Repurpose military surplus fabric into stylish purses and bags[124] is an example.
Wear2[125] process facilitates microwave textile disassembly, making it easy to debrand corporate clothing, remove labels from stock and prepare textiles such as clothing, car seats and mattresses for recycling. (*Until now, the lack of effective disassembly technologies and absence of design protocols for handling clothing at end-of-life have acted as a barrier in this regard.*)
Spider silks, biodegradable, stronger and tougher than steel, could be used for ballistic protection.[126]

7 Conclusion

The sustainable engineering is "the integration of social, environmental and economic considerations into product, process and energy system design methods". Industrialisation needs to be sustainable to ensure quality of life. The key sustainability challenges in fibre production[127] and in manufacturing practices to be addressed with a full-hearted outlook. Unsustainability elements had been set in motion as of no consequence inevitability in the early industrialisation process.

Defence T&C characterised with certain specific features met by a range of fibres, chemicals, and technical and management processes, which, for sustainability inevitability to be suitably look upon, encompassing the pillars of sustainability and duly accounting whole life cycle. Sustainable procurement process is capable of strengthening the sustainability phenomena. Tools and techniques as elucidated for twenty-first-century requirements are capable of substantiating sustainability efforts.

Some of the efforts as detailed below are positive approaches towards sustainable defence T&C[128]:

- Sourcing suppliers based on social and environmental performances;
- Substituting hazardous substances with safer substances;
- Inclusive information exchange with stake holders;
- Promoting more of sustainable fibres such as organic cotton, recycled fibres;

[124] http://daniellelvermeer.com/blog/upcycled-fashion-companies.
[125] http://www.ctechinnovation.com/funded-projects/wear2-microwave-textile-disassembly/.
[126] http://www.trustedclothes.com/blog/2016/05/18/the-future-of-sustainable-textiles/.
[127] Charlotte Turner, Reducing Environmental Impact, The Future of Fashion Fabrics—October 2012.
[128] http://ec.europa.eu/environment/industry/retail/pdf/issue_paper_textiles.pdf.

- Usage of various modus operandi capable of strengthening sustainability;
- Demanding suppliers to implement international social and environment standards;
- Using best practices.

The educational programmes on "Sustainable Management" and yearly "Textile Sustainability Conference" are capable of providing knowledge and skills on "green path" to transform the way that organisations do business for defence T&C.

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