Digitalizacija Volkswagen sustava proizvodnje

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MASTER'S THESIS

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DIGITALIZATION OF VOLKSWAGEN PRODUCTION SYSTEM

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I hereby declare that this thesis is entirely the result of my own work except where otherwise indicated. I have full cited all used sources and I have only used the ones given in the list of references.

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Naslov rada na hrvatskom jeziku: **DIGITALIZACIJA VOLKSWAGEN SUSTAVA PROIZVODNJE**

Naslov rada na engleskom jeziku: **DIGITALIZATION OF VOLKSWAGEN PRODUCTION SYSTEM**

Opis zadatka:

Industry 4.0 is a strategic approach of connecting systems based on the Internet technology with the aim of establishing communication between machines, people, products and production systems. This concept was presented for the first time in 2011 at the world industrial fair „Hannover Messe" as a part of the German industrial strategy for the period until 2020. The main objectives are: to create a smart factory and to digitalize business and production processes in order to increase the overall quality, reduce production costs, increase flexibility and production efficiency.

The assignment should include following subjects:
1. General description of digitalization.
2. Description of the global trends connected with digitalization.
3. Description of a process approach in enterprise, and comprehensive overview of improvement methodologies.
4. Description of lean management, and comprehensive overview of lean tools.
5. Description of a concept that integrates lean management and digitalization.
6. As an example, apply digitalization on at least one process of the Volkswagen production system.
7. Estimation of effects of a digitalization on a production system.

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ABBREVIATIONS

3D – three dimensional

AG –Aktiengesellschaft (German: corporation)

AR – Augmented Reality

BMBF – Bundesministerium für Bildung und Forschung (German: The Federal Ministry of Education and Research of Germany)

CIM – Computer Integrated Manufacturing

CPPS – Cyber-Physical Production System

CPS – Cyber-Physical System

DMAIC – Define-Measure-Analyze-Improve-Control

e-Kanban – electronic Kanban

HR – Human Resources

ICT – Information and Communication Technology

IoS – Internet of Services

IoT – Internet of Things

ISO – International Organization for Standardization

IT – Information Technology

JIT – Just-in-Time

M2M – Machine to Machine

MIT – Massachusetts Institute of Technology

MMI – Man-Machine Interaction

OEM – Original Equipment Manufacturer

OICA – Organisation Internationale des Constructeurs d'Automobiles (French: International Organization of Motor Vehicle Manufacturers)

OpEx – Operational Excellence

PDSA – Plan-Do-Study-Act

QR code – Quick Response code

RFID – Radio Frequency Identification

SF – Smart Factory

SPC – Statistical Process Control

tech – technology

TPS – Toyota Production System

TQM – Total Quality Management

VR – Virtual Reality

VW – Volkswagen

VW PS – Volkswagen Group Production System

WLAN – Wireless Local Area Network

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ABSTRACT

Digitalization is a megatrend which is defined as „*the adoption or increase in use of digital computer technology by organization, industry, country, etc.* [4]*"* Advances in technology create new opportunities today to improve or even re-invent businesses, industries and markets. Some of the most important enablers of digitalization are mobile internet, cloud technology, computational power, Big Data, Internet of Things, etc. [6]

The process of digitalization in manufacturing areas is referred to as "Industry 4.0" in Europe and it stands for the fourth industrial revolution of production. Industry 4.0 is a collective term which groups together: 1) all intelligent digital networks of different companies along the stages of value creation, 2) the autonomous, rule-based decision-making and 3) performance management of individual value creation functions within a company based on Big Data analytics.

Since digital technologies are widely accessible nowadays, companies must invest in them to redesign or reinvent products, services or business models so they do not get disrupted. Companies need to go through digital transformation to generate benefits from new technologies. Traditional companies need to rethink 5 domains of their business strategies: customers, competition, data, innovation and value.

Volkswagen AG is a company which has recognized the challenges of the automotive industry connected with digitalization and has responded to them with a new strategy. Volkswagen AG aims to raise funding for its strategy by improving operational excellence as one of its initiatives. Operational excellence includes the lean approach which stands for producing only what the customer wants by eliminating the waste in all processes and focusing on continuous improvement. Lean manufacturing is based on 5 principles which are nowadays being questioned in regard to Industry 4.0 concepts which promise similar benefits lean aims to achieve. The thesis has shown that the lean approach is the prerequisite of implementing Industry 4.0; and that the concepts and technologies of Industry 4.0 help lean to achieve its goals faster and easier.

KEY WORDS: digitalization, Industry 4.0, digital transformation, digital disruption, lean manufacturing, Toyota Production System, Volkswagen AG

ABSTRACT IN CROATIAN

(SAŽETAK)

Digitalizacija je megatrend koji se definira kao „*usvajanje ili povećanje uporabe digitalne računalne tehnologije u organizacijama, industrijama, zemljama, itd.* [4]*“* Tehnološki napredci omogućuju poboljšanje postojećih ili čak kreiranje novih poduzeća, industrija i tržišta.

Neke od najvažnijih tehnologija koje omogućuju digitalizaciju su: mobilni internet, računarstvo u oblaku, računalna snaga, Big Data, Internet stvari, itd. [6]

Proces digitalizacije proizvodnje se naziva Industrija 4.0 u Europi te se definira kao skupni pojam koji grupira: 1) sve inteligente digitalne mreže različitih poduzeća duž cijelog lanca stvaranja vrijednosti, 2) autonomno donošenje odluka na temelju pravila odlučivanja te 3) upravljanje učinkom individualnih faza dodavanja vrijednosti unutar poduzeća bazirano na Big Data analitici [29].

Budući da su digitalne tehnologije danas široko dostupne, poduzeća moraju ulagati u njih kako bi redizajnirala ili kreirala nove proizvode, usluge, ili poslovne modele te tako izbjegla digitalnu disrupciju.

Poduzeća moraju proći kroz proces digitalne transformacije kako bi generirala koristi omogućene korištenjem novih tehnologija. Tradicionalna poduzeća trebaju promisliti 5 domena poslovne strategije: kupci, konkurencija, podaci, inovacije i vrijednost [56].

Volkswagen AG je poduzeće koje ja prepoznalo izazove povezane s digitalizacijom u automobilskoj industriji te odgovorilo na njih novom strategijom. Volkswagen AG namjerava prikupiti financijska sredstva za novu strategiju kroz poboljšanje operativne izvrsnosti koja uključuje lean pristup koji se zalaže za proizvodnju samo onoga što kupac želi, eliminiranjem otpada u svim procesima i fokusiranjem na kontinuirano poboljšanje. Lean proizvodnja temelji se na 5 načela čija se važnost sada preispituje jer Industrija 4.0 obećaje postizanje sličnih pogodnosti koje lean želi postići.

Ovaj diplomski rad je pokazao da je lean pristup preduvjet za provedbu Industrije 4.0 i da koncepti i tehnologije Industrije 4.0 pomažu ostvariti ciljeve lean-a brže i lakše.

KLJUČNE RIJEČI: digitalizacija, Industrija 4.0, digitalna transformacija, digitalna disrupcija, digitalna strategija, lean proizvodnja, Volkswagen AG

EXTENDED ABSTRACT IN CROATIAN

(PROŠIRENI SAŽETAK NA HRVATSKOM)

Uvod

Digitalne tehnologije su dosegnule stupanj zrelosti koji omogućuje njihovo korištenje u brojnim industrijama, te danas gotovo da i nema industrije koje se ne bavi ovim megatrendom u pogledu njegovog utjecaja i budućih moćnosti koji s njime dolaze. U prošlosti, digitalne inovacije su uglavnom utjecala na IT industriju. Međutim, napredci u digitalnim tehnologijama su donijeli digitalnu revoluciju u proizvodnu industriju u kojoj digitalizacija ima utječe na sve proizvode, usluge i procese.

Digitalizacija proizvodnje se često naziva Industrija 4.0 koja je omogućena Internetom stvari te dovodi do međusobnog povezivanja strojeva i uređaja u tvoricama koje će omogućiti proizvodnim poduzećim ne samo da povećaju svoju produktivnost, kvalitetu, učinkovitost i odziv na promjene, nego i uvesti novu razinu prilagodbe proizvoda i usluga kupcima.

Ovaj diplomski rad se fokusira na uvođenje digitalnih tehnologija u poslovanje proizvodnih poduzeća što dovodi do novih načina poslovanja te do digitalne poslovne strategije.

Lean proizvodnja je široko poznati pristup u proizvodoj industriji koji se etablirao kao superioran pristup upravljanja proizvodnjom. Lean proizvodnja usmjerena je na stvaranje vrijednosti koja je definirana od strane kupca eliminirajući bilo kakav oblik otpada u svim procesima i kroz kontinuirano poboljšanje. Važnost lean filizofije je sada dovedena u pitanja jer digitalizacija obećava mnoge prednosti koje lean želi postići.

Digitalizacija

Digitalizacija je megatrend koji označava integraciju tehnologija u privatni i poslovni život ljudi. Pojam se definira kao „*usvjanje ili povećanje uporabe digitalne računulane tehnologije od strane organizacija, industrija, zemalja, itd*. [3]"

Pojam digitizacija se često koristi naizmjenično s pojmom digitalizacija što zbunjuje mnoge. Digitalizacija i digitizacija nisu isti pojmovi. Digitizacija se definira kao „*djelovanje ili proces digitizacije; pretvorba analognih podataka u digitalni oblik*" [3].

Najvažnije tehnologije koje omogućuju digitalizaciju su: mobilni internet, računarstvo u oblaku, računalna snaga, Big Data, Internet stvari, itd. [6]

Industrija 4.0

Zahtjevi tržišta koji uključuju kratko vrijeme dostave na tržište, individualizaciju proizvoda i usluga, povećanu fleksibilnost, decentralizaciju i učinkovitost resursa su okidači digitalizacije industrijske proizvodnje. S druge strane, nove pristupačne informacijske i komunikacijske technologije daju poticaj za digitalizaciju i omogućuju nove mogućnosti u proizvodnji [27].

Industrija 4.0 je skupni pojam koji grupira: 1) sve inteligente digitalne mreže različitih poduzeća duž cijelog lanca stvaranja vrijednosti, 2) autonomno donošenje odluka na temelju pravila odlučivanja te 3) upravljanje učinkom individualnih faza dodavanja vrijednosti unutar poduzeća bazirano na Big Data analitici [29]. Industrija 4.0 je mrežni pristup koji povezuje fizičke i digitalne procese u industrijskoj proizvodnji vertikalno i horizontalno što rezultira fuzijom proizvodnih te informacijskih i komunikacijskih tehnologija [30]. Najvažnija tehnološka područja Industrije 4.0 uključuju: kibernetsko-fizički sustav, pametne tvornice, sigurne mreže, računarstvo u oblaku i IT sigurnost [35].

Kibernetsko-fizički sustavi (CPS)

Kibernetsko-fizički sustavi su sustavi koji su nastali umrežavanjem već ugrađenih sustava te rezultiraju inteligentnim umrežavanjem ljudi, strojeva, proizvoda, predmeta te informacijskih i komunikacijskih sustava. Takvi sustavi omogućavaju koncept Industrije 4.0. Komunikacija CPS-a međusobno je omogućena Internetom stvari u stvarnom vremenu. Internet stvari se zato može definirati kao mreža u kojoj CPS-evi surađuju jedni s drugima putem jedinstvanih shema [35].

Pametna tvornica

„*Pametna tvornica predstavlja ključnu značajku Industrije 4.0* [29].“ Pametna tvornica je mjestu gdje su svi proizvodi, strojevi i cijelo okruženje povezani u mrežu čime je omogućeno dijeljenje informacija. To okruženje komunicira pomoću radio odašiljača ili podatkovnih oblaka na internetu ili intranetu tvornice. Takvi proizvodni kapaciteti imaju sposobnost dijagnostike i samoorganizacije. Osnovu pametne tvornice čine CPS-evi koji komuniciraju preko Interneta stvari [39].

Pametni proizvodi

Zbog sposobnosti komuniciranja, i proizvodi u pametnoj tvornici su „pametni“. Pametni proizvodi se mogu identificirati u stvarnom vremenu; oni znaju svoju povijesti, trenutni status i alternativne rute kako bi postigli svoje ciljano stanje [40]. Početni proizvod sadrži informacije koje se odnose na proizvodnju u obliku prepoznatljivom za strojeve, kao što je npr. RFID. RFID osigurava podatke za put proizvoda tijekom proizvodne linije i podatke za pojedine koraka. Takve informacije osiguravaju da se proizvod proizvede u pravom slijedu i na pravi način. RFID je samo jedan primjer tehnike prijenosa informacija. Ostali su: WLAN, kodiranje bojom, QR kodovi, Bluetooth [41].

Sigurne mreže

Komunikacijske bežične ili žičane veze omogućavaju umreževanje u pametnoj tvornici. Te mreže moraju biti sigurne te moraju osigurati prijenos velikog broja podataka u industrijskom okruženju kako bi se odluke mogle donositi u stvarnom vremenu [35].

Računarstvo u oblaku

Strojevi i uređaji koji postaju „pametni“ i internet stvari omogućavaju prikupljanje velikih količina podataka. Tradicionalne baze podataka ne mogu pohraniti i analizirati sve te podatke. Industrija 4.0 ovisi o brizini i skalabilnosti oblaka koji omogućava digitalizaciju zbog mogućnosti pohrane ogromnih količina podataka te analize tih podataka [43].

IT sigurnost

IT sigurnost je preduvjet za provedbu Industrije 4.0. IT sigurnost osigurava zaštitu podataka zaposlenika, poduzeća, poslovnih partnera i zaštitu komunikacije unutar i izvan poduzeća [45].

Karakteristike Industrije 4.0

Poduzeća koja surađuju, dobavljači, klijenti ili čak i odjeli u istom poduzeću su rijetko potpuno povezani. Industrija 4.0 omogućava nove vrste integracije.

1. **Vertikalna integracija i umrežena proizvodnja**

Vetikalna integracija odnosi se na pravila IT konfiguracije u pametnim tvornicama koja su definirana na takav način da automatski izgrađuju specifičnu proizvodnu strukturu ovisno o situaciji [29]. Time je omogućena fleksibilna proizvodnja koja se temelji na modularnim, autonomnim proizodnim jedinicama.Vertikalna integracije omogućena kibernetsko-fizičkim proizvodnim sustavom omogućava samoorganizaciju pametnih tvornica, tj. autonomnu organizaciju upravljanja proizvodnjom. [24].

2. **Horizontalna integracija mreže vrijednosti**

Horizontalna integracija predstavlja novu generaciju globalnog lanca vrijednosti. Lanac vrijednosti sastoji se od dobavljača, proizvođača, trgovaca i kupaca [29]. Horizontalna integracija, omogućena CPPS-ima uključuje umrežavanje svih procesa od ulazne logistike, skladištenja, proizvodnje, marketinga, prodaje, izlazne logistike i daljnjih usluga. Takvo umrežavanje omogućava praćenje bilo kojeg materijala ili proizvoda te njegove povijesti kojoj se može pristupiti u bilo koje vrijeme čime se postiže transparentnost, visoka razina fleksibilnosti te mogućnost bržeg reagiranja na greške i probleme [24].

3. **Digitalna integracija s kraja na kraj inženjeringa preko cijelog lanca vrijednosti**

Primjena CPS-a omogućava uspostavljanje integracije svih procesa od zahtjeva kupca, dizajna te izrade proizvoda pa do gotovog proizvoda. Takav novi pristup omogućava stvaranje proizvoda prema specifičnim zahtjevima kupaca. Time je moguće postići veće zavodoljstvo kupaca te smanjenje troškove proizvodnje zbog integracije cijelog lanca vrijednosti [29].

Digitalna disrupcija

Digitalne tehnologije su široko dostupne, što znači da ih svako poduzeće može koristiti i njihovim korištenjem postići konkurentsku prednosti. Poduzeća moraju reagirati na promjene na tržištu te osigurati svojim kupcima nove vrste proizvoda, usluga ili novu vrstu odnosa s kupcima što je omogućeno digitalizacijom. Ukoliko to ne učine, druga poduzeća mogu poremetiti njihovo poslovanje. „*Digitalna disrupcija je promjena u konkurentkon okruženju koja proizlazi iz korištenja digitalnih tehnologija od novih tržišnih sudionika ili već utvrđenih konkurenata na način da ometa održivost proizvoda / usluga ili go-to-market pristupa drugih poduzeća* [54].“ Prema tome, poduzeća moraju biti svjesna što se događa u njihovoj industriji i izvan nje te reagirati brzo na promjene. Stručnjaci tvrde da se mnoga poduzeća neće moći nositi s izazovima koji ih čekaju te da će „digitalna nesposobnost“ izazvati da jedno od četiri poduzeća izgubi svoj konkurentski rang [55].

Digitalna transformacija

Nove tehnologije i povećanje umreženosti predstavljaju izazove s obzirom na mogućnost digitalne disrupcije, ali nude i mogućnosti za povećanje vrijednosti svojih proizvoda ili usluga promjenom poslovnog modela i strateškog razmišljanja. Da ne bi došlo do digitalne disrupcije poduzeća, poduzeće mora proći kroz digitalnu transformaciju. Prema Davidu L.Rogersu, „*digitalna transformacija ne podrazumijeva ažuriranje tehnologija organizacije, već unapređenje strateškog razmišljanja*”[56]. S obzirom da digitalne tehnologije omogućuju promjene proizvoda, usluga, procesa, odnosa s kupcima i dobavljačima, jasno je i da se način poslovanja mora promijeniti. Konkurentnost na tržištu je često povezana sa sposobnošću prilagodbe poslovnih modela i strategija poduzeća promjenama na tržištu [61]. To je razlog zašto poduzeća moraju osmisliti digitalnu strategiju koja će se fokusirati na transformaciju proizvoda, procesa i organizacijskih aspekata zahvaljujući novim tehnologijama. Prema

Rogersu, poduzeća moraju promisliti slijedeće domene svoje strategije: kupci, konkurencija, podaci, inovacija, vrijednost.

Automobilska industrija u doba digitalizacije

Glavne promjene u automobilskoj industriji s kojima će se proizvođači automobila morati nositi uključuju sve veće zahtjeve kupaca, veću složenost proizvoda, te rast mreža dobavljača. Također, pored pritisaka od već postojećih konkurenata, na tržište ulaze i novi konkurenti koji će donijeti nove izazove. Većina stručnjaka automobilske industrije se slaže da postoje 4 megatrenda: nova rješenja mobilnosti, autonomna vožnja, elektrifikacija i povezanost automobila [73].

Volkswagen u doba digitalizacije

Volkswagen grupa, kao vodeći svjetski proizvođač automobila u 2016.-oj godini, prepoznao je izazove automobilske industrije te je na njih odgovorio transformacijskom strategijom „TOGETHER 2025“. Nova strategija grupe temelji se na: 1) transformaciji osnovnog poslovanja, 2) izgradnji poslovanja temeljenog na novim rješenjima mobilnosti, 3) osiguranju financijskih sredstava i 4) jačanju inovacijske moći [86]. Jedna od inicijativa osiguranja financijskih sredstava za strategiju je „Poboljšanje operativne izvrsnosti“. Operativna izvrsnost u Volkswagen grupi morati će osigurati financijska sredstva kroz poboljšanje procesa na svim razinama i funkcijama duž cijelog lanca vrijednosti [88].

Operativna izvrsnost

Operativna izvrsnost je program stalnog poboljšanja s ciljem postizanja konkurentske prednosti povećanjem vrijednosti za kupca koja rezultira postizanjem financijskog uspjeha [90, 91]. Metode koje se koriste za postizanje operativne izvrsnosti često uključuju metode osiguranja kvalitete, Six Sigma metodu te lean proizvodnju [92].

Lean proizvodnja

Lean pristup je temelj proizvodnog sustava Volkswagen grupe. To je pristup proizvodnji razvijen u Toyoti te se stoga Toyotin proizvodni sustav često i naziva „Lean proizvodni sustav“. Lean je „*filozofija koja služi za povećanje vrijednosti za potrošača uz minimiranje otpada*“. Jednostavno rečeno, lean stvara više vrijednosti za kupca korištenjem manje resursa [101].

Lean se temelji na 5 načela:

1. Utvrđivanje vrijednosti za kupca
2. Mapiranje toka vrijednosti
3. Ostvarenje protočnosti procesa
4. Uspostavljanje povlačenja („pull" sustava)
5. Težnja savršenstvu

Lean pristup proizvodnji promiče usvajanje procesnog pristupa te lean raspoznaje 8 vrsta otpada u procesima koji moraju biti eliminirani kako bi se postigla lean proizvodnja, a to su: prekomjerna proizvodnja, škart, nepotrebni pokreti, nepotrebne zalihe, prekomjerna obrada, čekanje, transport i nedovoljno korištenje potencijala zaposlenika.

Volkswagenov proizvodni sustav

Volkswagen je razvio svoj proizvodni sustav slijedeći primjer Toyote, na lean načelima. Volkswagenov proizvodni sustav obuhvaća sva načela, standarde, metode i elemente potrebne za svakodnevnu provedbu stabilnih procesa bez otpada kako bi se stvorilo sikrono poduzeće orijentirano dodavanju vrijednosti [114].

Volkswagenov proizvodni sustav temelji se na 4 načela [114]:

1. **Takt**: Proizvodi se samo ono što kupac treba te to načelo vrijedi u svim odnosima kupac-dobavljač. Kupac je taj koji definira ritam proizvodnje.
2. **Protok**: U idealnoj proizvodnj, materijal stalno teče, zalihe su smanjene, gubitci se mogu izbjeći i osigurano je kratko vrijeme ciklusa. Ovo načelo podrazumijeva da materijal i informacije teku prema taktu kupca.
3. **Povlačenje** („Pull"): Ukoliko nije moguće ostvariti stalan protok, ovo načelo omogućava dostavu u skladu s jasnim pravilima – samo ono što je potrošeno biti će proizvedeno. Time se sprječava prekomjerna proizvodnja.
4. **Savršenstvo**: Volkswagenov proizvodni sustav teži savršenstu u skladu s ciljem postizanja kvalitete bez greške.

Korelacija lean proizvodnje i digitalizacije

Informacijske i komunikacijske tehnoogije koje su danas dostupne i omogućuju digitalizaciju nisu postojale u vrijeme kada je Toyotin proizvodni sustav bio razvijen. Digitalizacija industrijskih procesa dovodi u pitanje važnost klasičnih principa. Jedno od dominantnih pitanja je trenutno da li lean metodologija i dalje može opstati u digitaliziranim proizvodnim poduzećima kao temelj proizvodnih sustava.

Implementacija digitalnih tehnologija u poduzeća i provedba lean pristupa donose slične pogodnosti. Digitalne tehnologije služe kao podrška postizanju zadovoljstva kupaca time što omogućavaju brže reagiranje na promjenjive potrebe kupca. Lean pristup odogovara na potrebe kupaca utvrđivanjem upravo onoga što kupac želi i isporukom te vrijednosti u pravoj količini i kvaliteti u pravo vrijeme i na pravom mjestu. Oba pristupa također rezultiraju optimiranim procesima što na kraju dovodi do gospodarskog uspjeha. Lean i digitalizacija imaju slične ciljeve, ali pitanje je da li lean načela mogu opstati u proizvodnim procesima obogaćenim tehnologijama i konceptima Industrije 4.0.

Lean i Industrija 4.0

Lean i Industrija 4.0 imaju isti cilj, a to je nalaženje rješenja u borbi s rastućom složenošću s obzirom da je nošenje sa složenoščću preduvjet za buduću konkurentnost velikog broja proizvodnih poduzeća [115]. Lean se fokusira na kontinuirano poboljšanje procesa tako što izbjegava otpad u procesima što rezultira povećanjem produktivnosti. S druge strane, Industrija 4.0 optimira procese tako što čini tvornice „pametnima“, povezujući sve proizvode, strojeve i cijelo okruženje, čime omogućava planiranje proizvodnje u stvarnom vremenu i dinamičku samoorganizaciju [116]. Osim povećanja produktivnosti, Industrija 4.0 omogućava individualizaciju zahtjeva kupaca, povećanje fleksibilnosti, dodavanje vrijednosti novim vrstama uslugama, optimirano odlučivanje i nove poslovne orgaizacije [29].

Osnovne ideje lean-a i Industrije 4.0 su vrlo slične, ali su im pristupi različiti.

Preduvjeti za implementaciju Industrije 4.0

Procesi u Industriji 4.0 moraju biti automatizirani, a to je jedino moguće ako su oni jasno definirani i ako su rezultati procesa mjerljivi, a kupci, dobavljači i resursi poznati. Industriju 4.0 jedino je moguće provesti, ako su procesi učinkovito projektirani i ako su odnosi kupac-dobavljač jasno definirani [120].

Lean kao preduvjet Industrije 4.0

Očito je da je procesni pristup preduvjet za Industriju 4.0. Koncepti Industrije 4.0 se jedino mogu provesti u proizvodnom sustavu koji je orijentiran prema kupcu. Optimizacija cijelog procesa dodavanja vrijednosti je fokus procesnog pristupa.

Lean promiče procesni pristup te dizajnira učinkovite procese orijentirane kupcu koji ispunjavaju preduvjet Industrije 4.0 s obzirom da automatizacija i digitalizacija same ne mogu optimirati neučinkovite procese. Neučinkovit proces koji je automatiziran ili podržan digitalnim tehnologijama i dalje ostaje neučinkovit proces. Lean procesi su temelj provedbe te preduvjet Industrije 4.0. Poduzeća moraju imati određeni stupanj zrelosti proizvodnog sustava koji se temelji na lean načelima prije provođenja tehničkih rješenja Industrije 4.0 [120]. Lean je preduvjet Industrije 4.0, ali pitanje koje ostaje neodgovoreno je, što se događa s lean načelima nakon provedbe koncepata Industrije 4.0.

Lean načela u Industriji 4.0

Lean načela se smatraju primjerom dobre prakse kada je u pitanju reagiranje na izazove dinamičnog tržišta, osobito u serijskoj proizvodnji zbog sposobnosti postizanja iznadprosječnih poslovnih uspjeha jednostavnim rješenjima, uglavnom bez IT podrške. Slijedećim primjerima će se odgovoriti na pitanje da li je moguće postići lean načela korištenjem koncepata i tehnologija Industrije 4.0.

1. **Utvrđivanje vrijednost za kupca**

Ko-kreacija s kupcima

Napreci u informacijskim i komunikacijskim tehnologijama omogućavaju ko-kreaciju. Ko-kreacija je proces u kojemu kupci rade zajedno s poduzećem u razvoju proizvoda ili usluga. Ko-kreacija može biti implementirana u bilo koju fazu razvoja te omogućava poduzećima da dobiju povratnu informaciju o proizvodima i uslugama u ranim fazama razvoja [122]. Ko-kreacija rezulira pogodnostima za poduzeće time što ono točno zna koji su zahtjevi kupaca; i pogodnostima za kupce koji na kraju dobiju točno onaj proizvod ili usluga koju žele [69].

Big Data analitika

Industrija 4.0 koristi tehnike za istraživanje potražnje na tržištu. Big Data analitika omogućava prikupljanje podataka generiranih od kupaca na društvenim mrežama, mobilnim uređajima ili drugim kanalima kako bi se analizirali neočekivani obrasci u poslovanju te se predvidjele i donijele bolje odluke s obzirom da se potražnja stalno mijenja. Big Data analitika se koristi kako bi se predvidjeli zahtjevi za nove proizvode ili za zamjenske dijelove.

Podaci s pametnih proizvoda

Pametni proizvodi su proizvodi koji npr. mogu biti kontrolirani raznim aplikacijama što generira podatke koje poduzeća mogu skupljati i analizirati Big Data tehnikama te ih koristiti za identifikaciju zahtjeva kupaca.

Nakon što poduzeće identificira kakve proizvode ili usluge kupci žele, digitalne tehnologije dodatno pomažu ponuditi nove vrste proizvoda, usluga ili odnosa sa svojim klijentima. Neke od mogućnosti su slijedeće:

- **Individualizacija proizvoda**

Industrija 4.0 postiže fleksibilnu i automatiziranu proizvodnju što omogućuje automatsko proslijeđivanje individualnih konfiguracija proizvoda u proces planiranja proizvodnje. Strojeve je moguće konfigurirati za vrijeme izvođenja proizvodnje tako da obrađuju pojedinačne radne naloge [36].

- **Pametne usluge**

Pametni proizvodi se često nude kupcima s odgovarajućim uslugama što je omogućeno novim digitalnim tehnologijama. Danas se kupovne odluke sve više donese na temelju usluga koje dolaze s proizvodima [56].

- **Usluge na zahtjev korisnika**

Posjedovanja predmeta postaje sve manje važno u odnosu na dostupnost predmeta na današnjem tržištu. Poduzeća mogu koristiti mogućnosti digitalnih tehnologija i osigurati nove načine poslovanja nudeći proizvode ili usluge na zahtjev te iste naplaćivati prema upotrebi.

2. **Mapiranje toka vrijednosti**

Pametne tvornice

Koncept pametnih tvornica povezuje sve dosad nepovezane automatizirane stanice tako što spaja cjelokupni proizvodni sustav, na npr. dijagnostiku i druge aplikacije za praćenje svih procesa i entiteta u tvornicama u realnom vremenu.Time se potiže transparentnost cijelog lanca vrijednosti te olakšano razlikovanje aktivnosti koje dodaju vrijednost od aktivnosti koje ne dodaju vrijednost.

Horizontalna integracija mreže vrijednosti

S obzirom da horizontalna integracija povezuje sve entitete lanca vrijednosti, ona omogućuje prijenos podataka između dobavljača, proizvođača, trgovaca i kupaca. Svaki od entiteta transparentno prima podatke o razinama opskrbe drugih entiteta te tako može automatski provoditi narudžbe ili aktivirati održavanje i nadogradnju [128]. Ovim konceptom je omogućeno automatsko mapiranje toka vrijenosti u cijelom lancu opskrbe.

Suradnička proizvodnja

Suradnička proizvodnja je koncept omogućen horizontalnom integracijom koji ujedinjuje različita poduzeća kroz cijeli lanac vrijednosti virtualizacijom lanca vrijednosti [127]. Time je postignuto sinkroniziranje svih sudionika u lancu vrijednosti te automatsko slanje povratnih informacija [116].

3. Ostvarenje protočnost procesa

Sustavi za pomoć

Protočnost procesa može biti narušena visokim postotkom škarta, čestim zaustavljanjem strojeva i sl. Jedna od mogućnosti stabiliziranja ciklusa proizvodnje u područjima u kojima radi mnogo zaposlenika je korištenje digitalnih i video sustava za pomoć radnicima kako bi se smanjio postotak ljudskih grešaka [129]. Takvi sustavi pružaju zaposlenicima informacije, upute ili čak video tutoriale čime se olakšava postizanje protočnosti procesa.

Prediktivno održavanje

Industrija 4.0 omogućava kontinuirano praćenje stanja cijelog proizvodnog sustava. Podaci o stanju strojeva se kontinuirano skupljaju sa senzora i dijele online čime se omogućava provjera stanja opreme i predviđanje korektivnog održavanja. Kada je vrijeme održavanja unaprijed poznato, planiranjem je moguće izbjeći pojavu uskog grla [130].

Kibernetsko-fizički sustavi

Kibernetsko-fizički sustavi omogućavaju praćenje inventara u stvarnom vremenu. Ukoliko u tvornici nema dovoljno resursa, pametna tvornica ima sposobnost donošenja decentraliziranih odluka te tražanje novih načina proizvodnje koji omogućuju kontinuirani protok i sprječavaju uska grla [116].

Internet stvari i označavanje robe

Internet stvari i ugrađeni uređaji za komunikaciju kojima se roba označava omogućavaju praćenje toka te robe. Svaki proizvod u svako vrijeme zna svoje mjesto, stanje i povijest. Npr. RFID omogućava bežično praćenje robe i otkriva ako neki predmet nije tamo gdje bi trebao biti te je time omogućeno reagiranje u stvarnom vremenu čime se smanjuje vrijeme čekanja na taj predmet i osigurava se da on stigne na odredište najboljim mogućim putem[116].

4. **Uspostavljanje povlačenja („Pull sustav“)**

E-Kanban

Nepravilno praćenje materijala ili promjena u rasporedu nakon opskrbe materijala može ozbiljno utjecati na „pull“ sustav proizvodnog sustava. Korištenje e-Kanaban sustava može omogućiti automatsko povlačenje i nadopunjvanje materijala. E-Kanban sustavi prepoznaju prazne kante materijala putem senzora te automatski pokreću nadopunjavanje [116].

Horizontalna integracija IT sustava

Horizontalnom integracijom IT sustava se postiže fleksibilnost i transparentnost tijekom cijelog toka vrijednosti. Dobavljačima je omogućen uvid u čitav lanac opskrbe čime je moguće automatizirati proces naručivanja, tj. pokretanja pojedinačnih proizvodnih naloga [116]. Kada pametna tvornica primi nalog, on se izravno proslijeđuje proizvodnim stanicama te on samostalno kontrolira proces proizvodnje čime je omogućen savršen sustav povlačenja.

5. **Težnja savršenstvu**

Big Data

Savršenstvo se prema lean-u postiže kontinuiranim poboljšanjima koja su moguća samo kada postoje definirani ciljevi. S obzirom da horizontalna i vertikalna povezanost omogućavaju transparentnost, podaci se mogu prikupiti sa senzora i računala te se ciljevi projekata poboljšanja mogu postaviti na temelju podataka iz stvarnog vremena, a ne iz prošlosti.

Strojno učenje

Tehnologija strojnog učenje će dovesti do povećanja samokontrole i samooptimizacije strojeva. Strojno učenje podrazumijeva mogućnost stroja da uči bez da bude izričito programiran. Strojno učenje automatski otkriva obrasce u podacima i koristi te obrasce za predviđanja i optimiranja, tj. za kontinuirano poboljšanje.

Ovi primjeri su pokazali da koncepti i tehnologije Industrije 4.0 omogućavaju brže i lakše postizanje lean načela ali i omogućavaju daljnja poboljšanja procesa time što povećava brzinu odziva prema promjenama u lancu vrijednosti što omogućava realizaciju istinskog lean poduzeća. Lean procesi su preduvjet za implementaciju Industrije 4.0 i da Industrija 4.0 omogućava postizanje lean ciljeva u potpunosti.

Posljedice digitalizacije na proizvodni sustav Volkswage AG-a

VW PS principles	Lean principles
Takt	Utvrđivanje vrijednosti za kupca
Tok	Ostvarenje protočnosti procesa
Povlačenje	Uspostavljanje povlačenja
Savršenstvo	Težnja savršenstvu

Tablica 1 Usporedba načela Volkswagenovog proizvodnog sustava i lean načela

Volkswagenov proizvodni sustav temelji se na 4 načela koja odgovaraju lean načelima kako je i prikazano u tablici 1. Drugo lean načelo, mapiranje toka vrijednosti, odgovara Volkswagenovom cilju „dosljedne eliminacije bilo kakvog otpada“. S obzirom da su načela Volkswagenovog proizvodnog sustava temeljena na lean načelima, te osiguravaju postizanje pouzdanih i efikasnih procesa koji su preduvjet za Industriju 4.0, može se zaključiti da se koncepti i tehnologije Industrije 4.0 mogu implementirati na temelju tih načela. Načela Volkswagenovog proizvodnog sustava će i dalje imati važnu ulogu u Industriji 4.0 te će Industrija 4.0 pomoći Volkswagenu realizirati svoja ciljeve u potpunosti te povećati brzinu reagiranja na promjene duž cijelog lanca vrijednosti.

Zaključak

Ovim diplomskim radom pokazano je da su lean načela i dalje potrebna u doba digitalizacije s obzirom da nije moguće digitalizirati procese koji nisu lean. Digitalizacija sama ne može poboljšati procese, a i njen glavni preduvjet je procesni pristup u poduzeću i efikasni procesi koji se postižu lean pristupom. Proizvodni sustav temeljen na lean načelima stvara odličnu osnovu za digitalizaciju, tj. za implementaciju Industriju 4.0 u proizvodnji. S druge strane, korištenje digitalnih tehnologija osigurava ostvarivanje svih 5 lean načela i postizanje lean poduzeća.

1. Introduction

Digitalization has already changed the economy in many ways with the digital technologies and online services evolving at an unseen speed. Since digital technologies have reached a degree of maturity that allows their use across a wide range of industries, there is hardly any industry that is not addressing this megatrend regarding its impact and future chances. Digitalization has been changing everything from personal relationships through social media to working with robots in production.

In the past, digital innovations mostly found its impact in the IT industry, but the recent and ongoing digital advancements have now brought the digital revolution to the manufacturing industry where digitalization affects all products, services and processes. When talking about digitalization in production and logistics, digitalization is often referred to as Industry 4.0 which is enabled by the Internet of Things and leads to extensive interconnection of machines and devices in factories and enables companies not only to increase their productivity, quality, efficiency as well as responsiveness, but also to introduce a new level of product customization.

The ongoing trend provides a major stepping stone for manufacturing companies as it forms the basis for the so-called smart factories (SF) but also allows them to entirely rethink their products and business models as digitalization transforms every essence of their business.

Many believe that the concept of digitalization will enable companies and industries to reach a higher degree of productivity and therefore increase their competitiveness. On the other hand, digitalization along with the continuous trend of globalization, poses a challenge for many companies.

Most of the companies across almost every industry are now challenged to transform their businesses. Digital transformation, hereby, stands for the use of digital technologies with the goal to create revenue. Companies across industries are now implementing digitalization strategies and changing their business models to answer to the changes and new challenges on the market.

This thesis will focus on manufacturing companies and the implementation of digital technologies in their businesses which shall then result in new possibilities of process optimization. In manufacturing, lean manufacturing is a wide-known approach which has established itself as a superior approach to management. Lean manufacturing focuses on creating value which is defined by the customer by eliminating any form of waste in all processes and through continuous improvement. The importance of lean philosophy is now being questioned since digitalization promises many of the benefits lean aims to achieve.

1.1. Thesis outline

In the first part of the thesis, the term digitalization will be defined, as well as the technologies which enable digitalization in companies. Then, the concept of Industry 4.0 will be described along with the technologies which are the enablers of the concept.

The terms digital disruption and digital transformation will be discussed. Due to the fact that digital transformation can be very expensive for the companies, lean manufacturing will be discussed as a possible approach to achieve the necessary cost reductions which in turn shall provide the funding for the digital transformation.

The thesis will also aim to address the correlation between lean and digitalization by answering the question whether lean approach is still required and suitable in the digitalization era. The question shall be answered by referring to examples of manufacturing companies using Industry 4.0 concepts in order to respond to the main challenges which are to shorten time to market, increase flexibility and boost efficiency, agility and speed.

The “TOGETHER – Strategy 2025” of Volkswagen AG will be given as an example of a digitalization strategy. In this context, the Volkswagen Production System will be described and the thesis will aim to answer the question of how the principles of this production system, which are based on the lean principles, will be affected in the digitalization era.

2. Digitalization

There is currently no other technical trend influencing our lives more than digitalization. Digitalization is an emerging megatrend which stands for the integration of multiple technologies into people´s work and daily lives which promises to bring fundamental changes.

The digital world has already affected all aspects of our lives. Analysts and scientists often compare digitalization and the omnipresent changes it brings across all industries to the industrial revolution enabled by the Internet [1].

Digitalization cannot only be thought of as the use of digital technologies. Experts claim that digitalization has the possibility not only to improve businesses and business processes, but also products and services in order to create revenue. In other words, digitalization will harness the power of technology to bring value.

Information and communication technologies which are the enablers of digitalization were already used in the past in order to support existing processes, such as logistics, purchasing and sales, marketing and customer relationship management. But today, those technologies serve to fundamentally develop new business models, products and services [2]. Digitalization changes consumer markets, but also has a massive influence on business-to-business markets which shall be discussed later.

2.1. Digitalization definition

Digitalization and digitization are two terms often used interchangeably in literature which oftentimes causes confusions. These terms, however, do not have the same definition and there is a clear line that separates them. In order to avoid confusion, the definitions of both terms are given below.

Digitalization and digitization are terms associated to each other. The Oxford English Dictionary defines digitization as "*the action or process of digitizing; the conversion of analogue data (esp. in later use images, video, and text) into digital form*". The same Dictionary defines digitalization as "*the adoption or increase in use of digital computer technology by an organization, industry, country, etc*. [3]"

The Gartner glossary defines digitalization as "*the use of digital technologies to change a business model and provide new revenue and value-producing opportunities; it is a process of moving to a digital business*" [4].

Both searches on the term digitalization and the term digitization are on the rise as shown on the figure below, where the graphs illustrate the interest over time for the terms on Google Search.

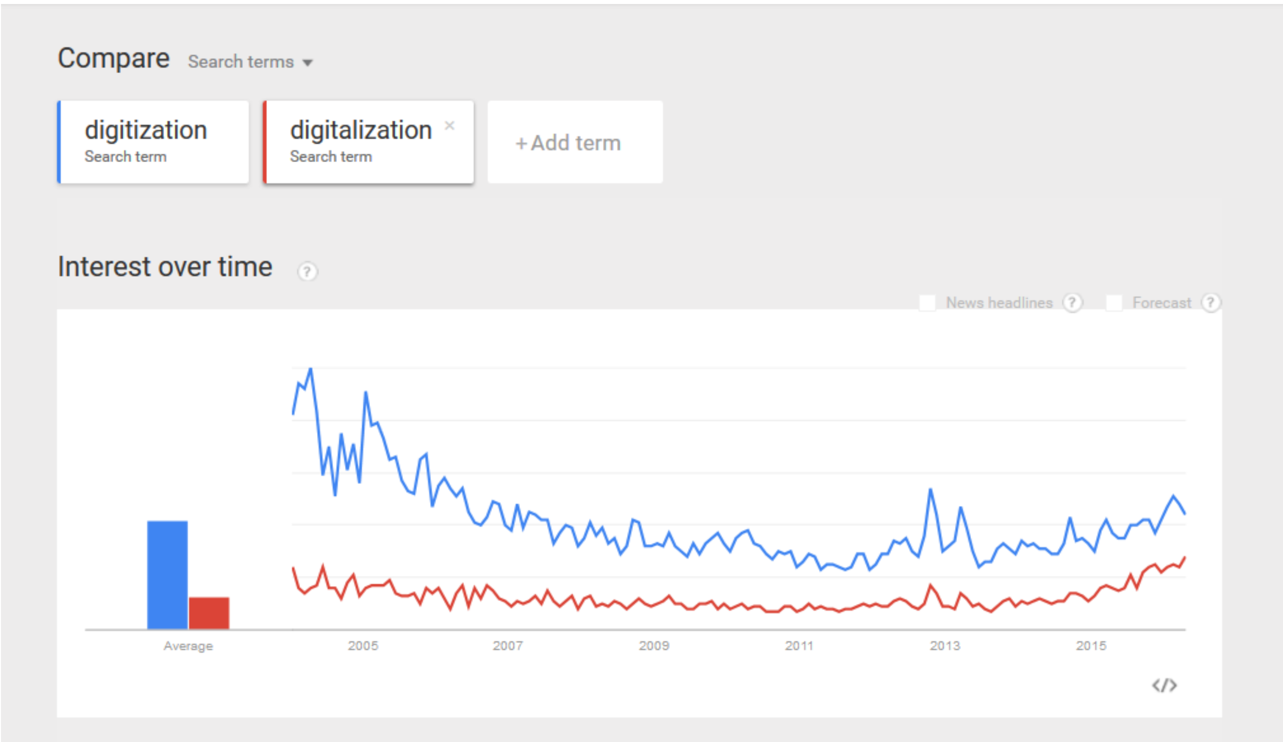

Figure 1 Interest over time for the terms digitization and digitalization [5]

2.2. Digital technologies and services as the enablers of digitalization

The advances in technology have always created new opportunities to improve businesses or to even re-invent them. Digital technologies are now the enablers of digitalization of organizations, industries, countries, etc. Their use will reshape businesses, industries and markets. According to the report "The Future of Jobs" by The World Economic Forum from January 2016, the major drivers and the enablers of digitalization identified by senior executives are the following [6]:

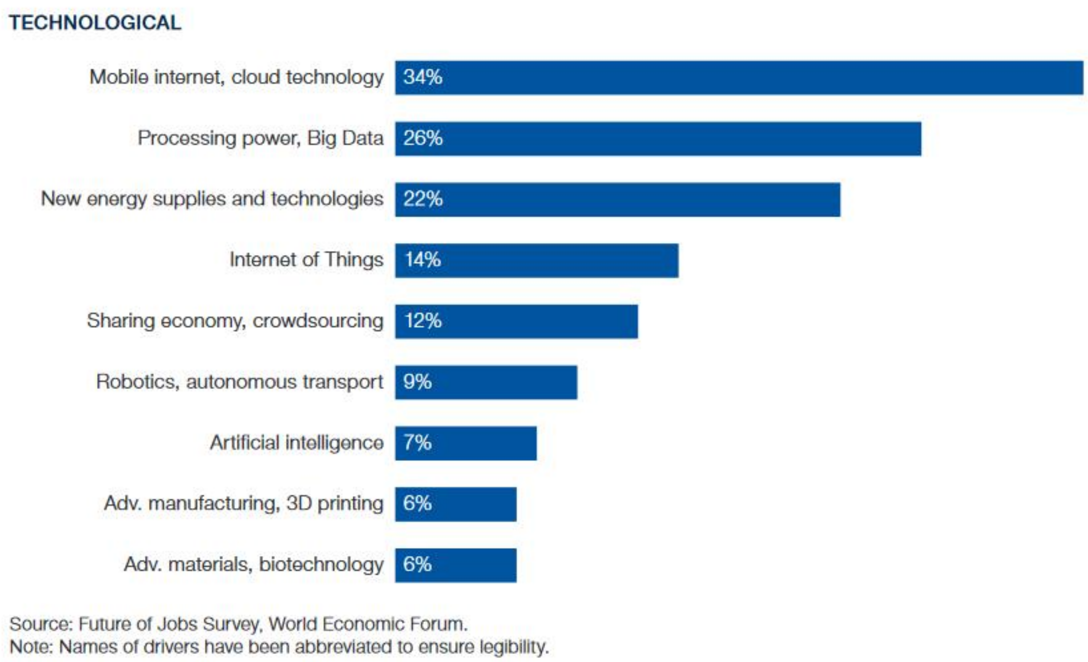

Figure 2 Technological drivers of digitalization [6]

2.2.1. Mobile internet and cloud technology

Mobile internet

Mobile internet makes it possible to take work out from the office, to access information anywhere and it allows people to interact with their environment and therefore make decisions which increase the workforce productivity. Mobile internet also enables companies to use mobile devices as valuable marketing channels to reach their customers and enable them to search for new products, learn about them and in the end buy them from anywhere in the world.

Cloud technology

Cloud technology is a general term for the delivery of hosted services over the internet [7]. It is a reliable and stable technology which can deal with a huge number of interconnected devices [8]. According to Kremp, there will be over 200 billion interconnected devices by the end of the decade [9].

Cloud technology enables outsourcing of complex applications, constant availability of data and services and their use on any device with minimal or no local software or processing power, enabling the rapid spread of Internet-based service models [6]. It gives the flexibility to respond to market opportunities, to improve the accessibility of the company´s brand and it makes it easier to do business [10]. The cloud is the basis for the digitalized business models and processes and will play a pivotal role in businesses in the future [8].

2.2.2. Advances in computing power and Big Data

Big Data

Nowadays, data is being generated rapidly by everyone. The respondents in the report also recognized the importance of Big Data for their industries. The term Big Data describes large quantities of data, obtained from different analog and digital data sources, which can no longer be evaluated with manual data processing methods because of their complexity. The level of their complexity is characterized with size or volume, diversity or heterogeneity and speed with which they arise.

The amount of collected data and the information generated from it can be used in a wide range of areas: from simple digital communication to the growing data retention, to the automation of production and decision-making processes. Every day around 2.5 exabytes of data are generated [11] which equals to the amount of data which would fill 10 million Blu-ray discs [12].

Computing power

Big Data needs enormous storage space and a great computing power, or in other words, it needs Big Computing. Big Data analytics would not be possible without the advances in computing power which were predicted by Moore in 1965. Moore´s Law predicts that there is a non-stop exponential growth in computing power and capacity which forms the basis for Big Data analytics.

Altogether, these advances help companies turn data into a business asset.

2.2.3. New energy supplies and technologies

Many companies are inventing new technologies and new ways to extract energy. New energy supplies and technologies, such as renewable energy and hydraulic fracturing are disrupting powerful companies with profound and complicated geopolitical and environmental repercussions [6].

2.2.4. Internet of Things

The Internet of Things (IoT), also called the "Internet of Everything" is a technology which enables a big amount of devices to be networked together wirelessly. It enables new possibilities between different devices and systems.

With the Internet of Things, it is possible to manage everything from anywhere, to reduce complexity and hardware costs with one network technology and to move control and information at will [13]. Internet is the core and the foundation of Internet of Things. Every single thing becomes a terminal user that can communicate with other users. The Internet of Things enables the communication of things to people, things to things and machines to machines.

2.2.5. Sharing economy, crowdsourcing

Sharing economy

Sharing economy is a term which has a lot of meanings, often used to describe economic and social activity involving online transactions. The term is also known as collaborative economy or consumption and peer economy [14].

Sharing economy evolved from the trend of objects becoming less important to people than their availability, especially among younger people. Sharing economy stands for resource, knowledge and experience sharing and is enabled by the internet. The core idea of sharing economy is to accomplish sustainability through sharing.

It leads to new forms of economic value exchange and it extends existing models from the micro- and macro-economic perspective [15].

Crowdsourcing

Crowdsourcing is a part of sharing economy. The term, coined by Jeff Howe in 2006, is a problem-solving model based on outsourcing work in a distributed way via an open call to a network of people, the so called crowd [16].

In crowdsourcing, anyone can propose groups of individuals a voluntary undertaking of a task. The crowd can participate in the task by bringing their work, money, knowledge and/or experience which can serve for mutual benefit. When the task is fulfilled, the group of individuals receives the satisfaction which can be economic, social recognition, self-esteem or personal development; and the crowdsourcer will use the advantage that the crowdworker brought to the venture [17].

Crowdstorming

A term connected with crowdsourcing is crowdstorming. It is a mix between brainstorming and crowdsourcing. Crowdsourcing can be external and internal. In external crowdstorming companies gather ideas from the outside, from customers for example. The public is called upon to submit ideas, comments or anything else that might be helpful to a company. Internal crowdstorming is similar; it enables organizations to gather ideas, thoughts and inputs from their employees [18].

2.2.6. Advanced robotics and autonomous transport

Advanced robotics

Advanced robots are robots which have enhanced senses, dexterity and intelligence [6]. Robots with enhanced senses have the sense of sight or touch for example, which expands robot´s application range. Dexterity enables robots to be able to manipulate objects similar like humans do, especially with their hands. A lot of research in robotics focuses on artificial intelligence which would make robots capable of almost everything humans do. Such robots are more practical than human labor in manufacturing [6].

Autonomous transport

Also, the development of autonomous driving or self-driving is accelerating and already today it is possible to create cars, trucks, aircraft and boats that are completely or partly autonomous which could revolutionize transportation, if regulations allow, as early as 2020 [6].

Autonomous driving allows passengers to use the time while travelling. Many car manufacturers also claim that autonomous driving will ensure more safety on the road and will enable a more steady flow of traffic and emissions.

2.2.7. Artificial intelligence and machine learning

Advances in artificial intelligence, machine learning and natural user interfaces (e.g. voice recognition) will make it possible to automate tasks humans do nowadays. Even the tasks which have been regarded as impossible or impractical for machines to perform will be able to become automated in the future [6]. Artificial intelligence is especially becoming more and more important in processes involving decision making.

Intelligent cognitive assistants

Intelligent cognitive assistants are systems which employ cognitive technology to interact with people and make their lives easier. Cognitive assistants use the technologies of natural language understanding and generation, semantic decomposition, machine and deep learning.

They can provide access to complex information, perform digital tasks, make recommendation about products or services, and bring awareness of context to an interaction. Companies can assemble them as needed to address particular interaction needs with customers, suppliers, or employees [19].

Machine learning

Machine learning refers to the ability of computer systems to improve their performance by exposure to data without the need to follow explicitly programmed instructions. At its core, machine learning is the process of automatically discovering patterns in data in order to use those patterns to make predictions [19].

Data mining

Data mining is a blend of concepts and algorithms from machine learning, statistics, and artificial intelligence to data management [20]. Data mining algorithms extract knowledge from a large volume of data which may be used for different applications. There are 2 classes of data mining: descriptive and predictive. The goal of descriptive data mining is to discover patterns, whereas predictive data mining aims at building models to predict outcomes [21].

Data mining can then lead to significant improvements in the next generation of products and services. Knowledge discovery could become the key factor to the innovation and business success. The goal of data mining may range from obtaining a general understanding of the nature of data to very accurate modeling and prediction [21].

2.2.8. Advanced manufacturing, 3D printing

Advanced manufacturing

A new range of technological advances in manufacturing technologies will enable new possibilities in manufacturing. Advanced manufacturing technology is "*a family of activities that depend on the use and coordination of information, automation, computation, software, sensing, and networking, and/or make use of cutting edge materials and emerging capabilities enabled by the physical and biological sciences, for example nanotechnology, chemistry, and biology. This involves both new ways to manufacture existing products, and the manufacture of new products emerging from new advanced technologies* [22]."

3D printing

3D printing or additive manufacturing is a technology which turns 3D models into solid objects by building them up in layers [23]. 3D printing allows new production solutions such as higher product complexity and functionality with no waste. Further it allows new supply chain solutions such as inventory reduction, faster delivery times or a combination of both that lead to disruptive new business models. 3D printing can accelerate the transformation of manufacturing companies as it makes the manufacturing process accelerated and more flexible [24].

2.2.9. Advanced materials, biotechnology and genomics

Technological advances in material and life sciences have brought many innovative industry applications. Some of the advances include self-healing and shape-shifting materials.

Self-healing materials

Self-healing materials are artificial or synthetically-created substances that have a built-in ability to automatically repair damage to themselves without any external diagnosis of the problem or human intervention. Some self-healing materials are categorized as smart structures and can adapt to various environmental conditions according to their sensing and actuation properties [25].

Shape-shifting materials

Shape-shifting materials are materials which can change their shape over time. They will enable a wide range of new applications and extend existing applications of current materials since it will be possible to use them in very tight and difficult accessible spaces. That is why they will even find their application in medical purposes, as biomedical implants [26].

2.3. Digitalization in manufacturing areas – Industry 4.0

Conditions of the global economy are changing. The changing customer demand which includes short time to market, individualization of products and services, increased flexibility, decentralization and resource efficiency are the triggers for digitalization of industrial production. On the other hand, new information and communication technologies such as affordable but powerful sensors and actuators are giving a push for the digitalization by enabling new possibilities in production [27].

The process of digitalization in manufacturing areas is referred to as "Industry 4.0" in Europe or as "Smart Manufacturing" in the U.S. The term Industry 4.0 originates from Germany where it was first introduced in 2011 at Hannover Fair as a part of a high-tech strategy of the German government. The term Industry 4.0 stands for the fourth industrial revolution or the digitalization of production.

According to the BMBF, Industry 4.0 is a collective term which includes the technologies and concepts of value chain organization [28]. The term groups together all intelligent digital networks of different companies along the stages of value creation and the autonomous, rule-based decision-making and performance management of individual value creation functions within a company, based on Big Data analytics [29].

It is a network approach which connects the physical and digital processes in the industrial production vertically and horizontally. This results in a fusion of production and information and communication technologies. Industry 4.0 is therefore characterized by the connection of machines, people, objects, and information and communication systems. The definition shows how extensive and comprehensive the term Industry 4.0 is. It is expected that such industrial revolution will result in a new level of organization and control over the entire value chain of the life cycle of products [30].

Industry 4.0 is geared to individualized customer wishes and it encompasses all phases from the idea and order to development and production, delivery of product to the end customer, even recycling and related services [30].

The integration of the Internet of Things (IoT) and the Internet of Services (IoS) in the manufacturing process has initiated the fourth industrial revolution according to Kagermann [29].

Internet of Things

Industry 4.0 would not be possible without the already defined Internet of Things since it is the enabler of the interaction and cooperation of all "smart" components such as sensors, actuators, mobile phones, etc. which aim to reach a common goal [31].

Internet of Services

The Internet of Services consists of participants, an infrastructure for services, business models and the services themselves. Those services are offered and combined into value-added services by various suppliers. They are provided to users and consumers via various channels [32].

Internet of Services allows a new way of dynamic variation of the distribution of individual value chain activities [33]. The use of the Internet of Services will enable factories not only to offer their production types, but to also offer special production technologies over the IoS [34].

2.3.1. Industry 4.0 main technology fields

As defined by Bauer W. et al. there are 5 main technology fields when talking about Industry 4.0 as shown on the figure below [35]:

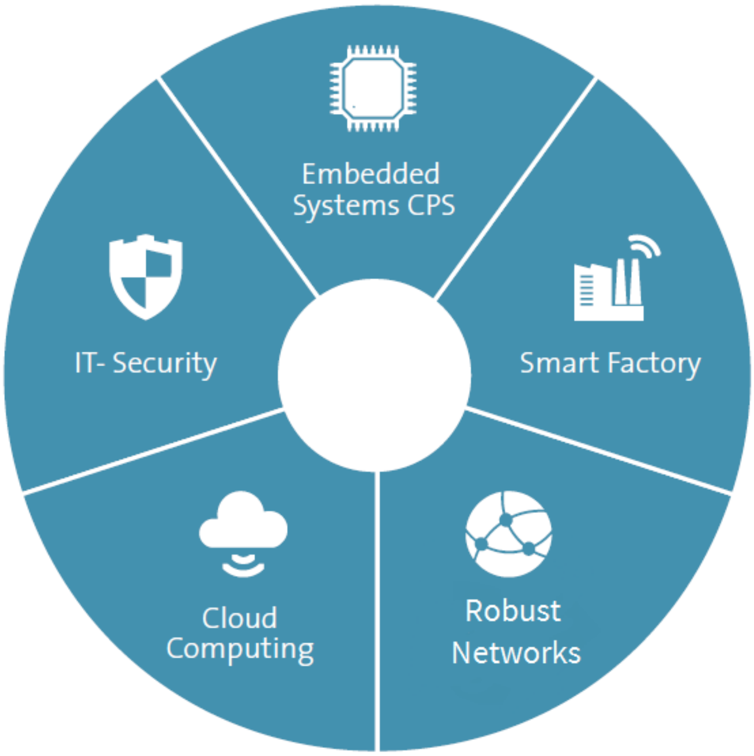

Figure 3 Five main technology fields in Industry 4.0 [35]

1. Embedded Systems, intelligent objects and Cyber-Physical Systems (CPS)

Embedded systems

Embedded systems are systems of previously passive equipment embedded with microcontrollers, communication systems, identifiers, sensors and actuators. Embedded systems are the basis for intelligent networking.

Communication systems embedded in such systems ensure interactions with radio and / or cable-based networks. Embedded sensors provide data regarding the direct environment of the objects. Identifiers are used to identify objects. An example of such identifier is a barcode or an RFID transponder which enables "things" to communicate in real time via radio waves with manufacturing systems. Actuators serve to perform movements of components of objects and also serve to transmit visual or acoustic information to people. Microcontrollers represent the actual intelligence of the embedded system. They analyze the incoming data, determine the status of an object, prepare decisions and execute them [35].

Cyber-Physical Systems (CPS)

Networking embedded systems are called Cyber-Physical Systems and they are created by the intelligent networking of people, machines, products, objects and information and communication systems. They are the new generation of embedded systems as shown on the figure below [35].

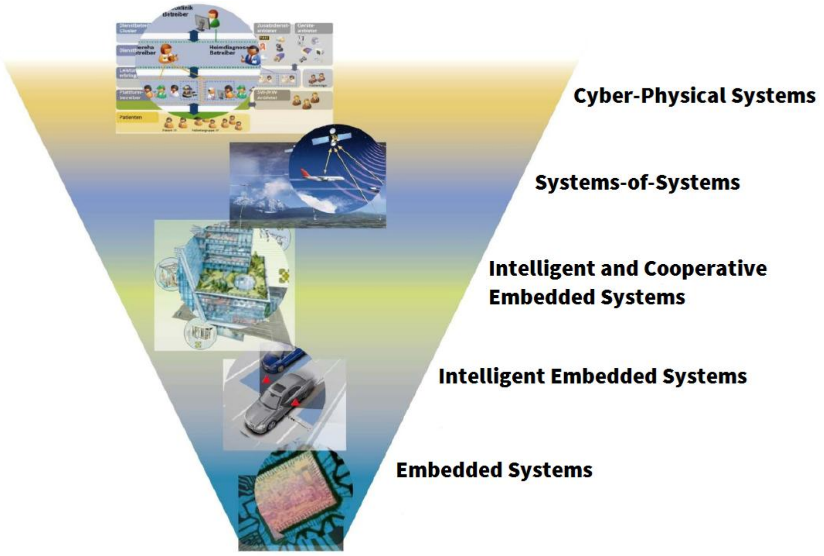

Figure 4 The evolution of Cyber-Physical Systems [36]

They analyze their environment with sensors and assess the impressions they receive by accessing globally available data and services [37]. The Cyber-Physical System has been seen as the enabler for Industry 4.0.

The communication of CPSs among each other is enabled by the Internet of Things in real-time. That is why the fourth industrial revolution would not be possible without the integration of the Internet of Things. Since the Internet of Things connects CPSs which are systems of “things” and “objects”, Internet of Things can also be defined as a network in which CPSs cooperate with each other through unique addressing schemes [36].

According to the definition of Vogel-Heuser et al. a CPS is defined as an embedded system which [35]:

- directly detects physical data by the means of sensors and acts on physical processes by the means of actuators;
- evaluates and stores data, and on that basis interacts actively or reactively with the physical and digital world;
- is interconnected by means of digital networks, both wireless and wired, both locally and globally;
- uses worldwide available data and services;
- has a number of multimodal man-machine interfaces, providing communication and

2. Smart factory

“*Smart factories constitute a key feature of Industry 4.0* [29].” A “smart factory” or an “intelligent factory” is the place where all products, machines and the whole environment are networked. This extensive networking enables them to share information among each other.

The environment communicates by means of radio transmitters or data clouds on the intranet or internet of the factory. The production facilities have diagnostic and repair capabilities so that the smart factory can organize itself.

There are multiple enablers needed for a smart factory: the devices which compose the systems, the connectivity to enable their integration, well targeted services and appropriate data as a foundation for digitization, visualization and analytics [38]. The technical bases for the smart factories are the CPSs which communicate with each other using the IoT [39].

Smart products

Because of the ability to communicate, the products in a smart factory are also "smart" and are called "smart products". Smart products can be identified and located in real-time; they know their history, current status and alternative routes to achieve their target state [40].

The starting product contains information relevant for production in a machine-readable manner on a chip, e.g. Radio-frequency identification (RFID) chip. RFID provides the data for the path of the product through the production line and the individual steps. Such information ensures that the product is manufactured in the right sequence and in the right way. RFID is just one example of a transmission technique. Others include: WLAN, color coding, QR codes and Bluetooth [41].

Industry 4.0 requirements on smart factories:

Decentralization

The goal of Industry 4.0 is to create decentralized smart factories which will have the full autonomy and will be able to make decentralized decisions which is becoming of more and more importance since there is a rising demand for individualized products. The basis for decentralization is the CPS which can make decisions autonomously on the basis of the real time gathered data and can therefore reduce planning efforts and complexity [42].

Virtualization

CPS will enable the virtualization of smart factories which means that the smart factory will have its virtual copy created by linking sensor data (from monitoring physical processes) with virtual models and simulation models [42]. Since there will be a virtual model of the smart factory, in case of any failure, people can be notified and all necessary information, such as next working steps or safety arrangements will be provided [40].

Real-time capability

It is necessary that the data is collected and analyzed in real-time in the smart factory so that the status of the plant could be permanently tracked and analyzed. In such way the plant can react to the failure of a machine or reroute products to other machines [36].

The basis for the development of new methods for a smart factory is the real-time image of the plant. Such “real-time image” enables direct process control and decision-making [35].

3. Robust networks

Real-time cable- and radio-based communication networks are the focus of the intelligent networking in the smart factory. The broadband networks form the backbone for Industry 4.0 applications in the factory. Such networks have to be secure and provide high data transmission rates with high data volumes in the industrial environment and have to be capable of real-time operation [35].

Radio-based networks also play an important role in dynamic production and logistics environments. While wireless local area networks are used in in-house area, the available mobile networks can be used in the non-operational area. In connection with radio-based communication, it is possible to use mobile end devices such as smart phones or tablets, which allow a direct integration of humans into the communication networks of a smart factory [35].

4. Cloud computing

Since machines, products and other objects are becoming “smarter” and the IoT technology enables the collection of large amounts of data, Industry 4.0 relies on the speed and scalability of the cloud since traditional databases are unable to store and analyze all the information [43].

Cloud computing offers opportunities to develop and use new methods for the analysis, planning, regulation and optimization of smart factories. Another application of the cloud is the provision of individual applications for the factory which means that all people can access the newly developed methods, algorithms and apps and have to adapt them only for the current application and no longer develop them again [35].

5. IT security

IT security regarding information and communication systems of Industry 4.0 technologies represents a relevant factor in the design of systems [44]. IT security is a prerequisite for the implementation of Industry 4.0. Data protection and a trustworthy treatment of data of employees, companies and business partners and a reliable protection of inter-company communication from external attacks has to be ensured and the access to the industrial internet has to be secured [45].

2.3.2. Industry 4.0 characteristics

Companies are rarely closely linked with other companies they work with, their suppliers and their customers. Even the departments in the same company often lack complete integration. Industry 4.0 enables companies, departments, functions and capabilities to become much more cohesive as cross-company, universal data-integration networks evolve and enable truly automated value chains [46]. Industry 4.0 consists of 3 main characteristics [29]:

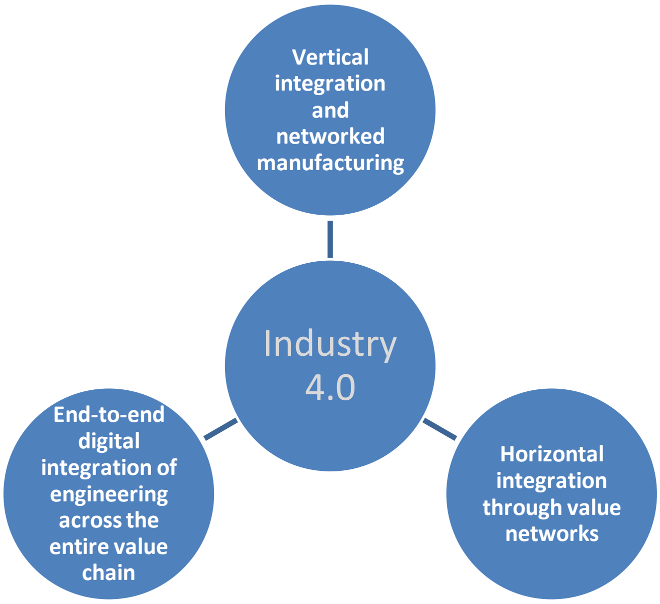

Figure 5 Main characteristics of Industry 4.0

All of those characteristics share one trait and that is that they take place in real-time [29].

Vertical integration and networked manufacturing

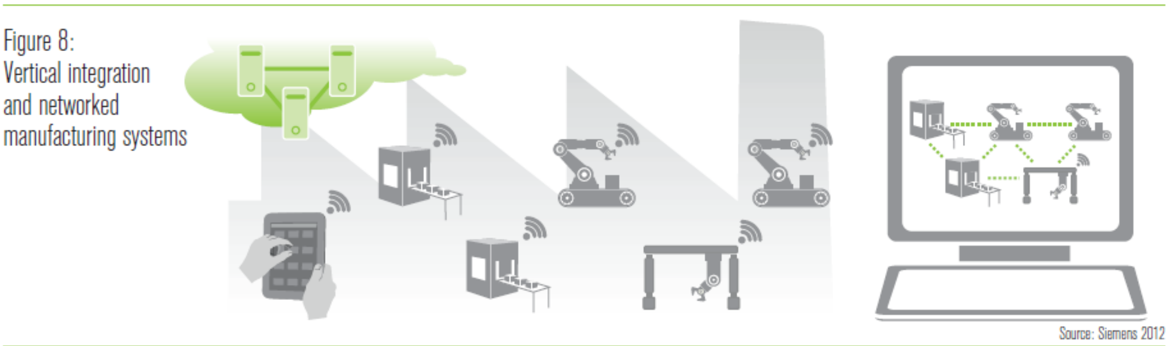

Figure 6 Vertical integration and networked manufacturing [29]

One of the main characteristics of Industry 4.0 is the vertical integration and networked manufacturing of smart production systems in the factories. Vertical integration refers to IT configuration rules in the smart factories which are defined in such a way that they can be used on a case-by-case basis to automatically build a specific structure depending on the situation [29]. In such way, flexible production based on modular, autonomous production units will be enabled.

The networked manufacturing is established by the use of Cyber-Physical Production Systems (CPPS) which consist of M2M (machine to machine) communication, MMI (man-machine interaction) and virtual reality (VR) or augmented reality (AR) which enable plants to rapidly react to changes in demand or stock levels and to faults [24, 47].

Cyber-Physical Production Systems are Cyber-Physical Systems which are deployed in industrial production. Cyber-Physical Production Systems allow smart factories to organize themselves when the data is integrated and they enable autonomous organization of production management. The requirement for the self-organizing and autonomous smart factory is smart sensor technology [24].

The aim of the CPPS is to provide a complete process chain throughout the entire product life cycle in order to increase flexibility and efficiency of industrial production in the long term [29]. The CPPS also enables maintenance management as the result of networked resources, products, materials and parts that can be located anywhere, anytime. Since all the processes are logged and the discrepancies are registered automatically, it is possible to deal with amendments to orders, fluctuations in quality or machinery breakdowns more rapidly which reduces waste. A significant emphasis is on resource efficiency which includes the efficient use of materials, energy and human resources [24].

Horizontal integration through value networks

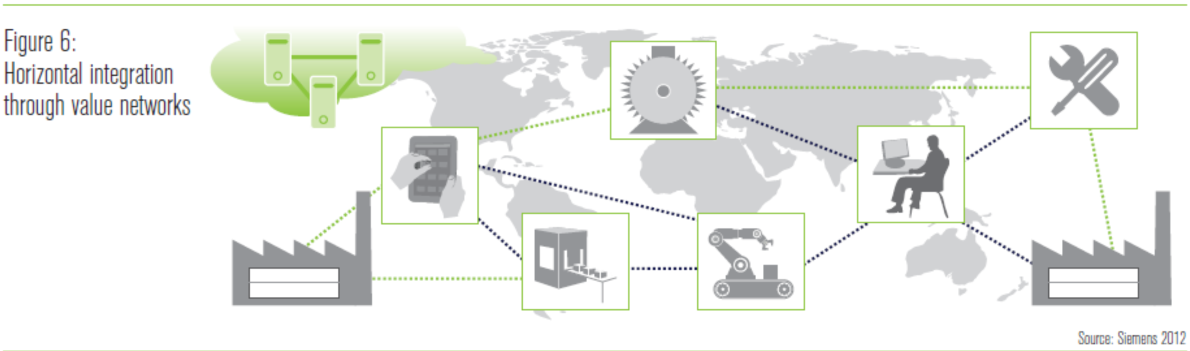

Figure 7 Horizontal integration through value networks [29]

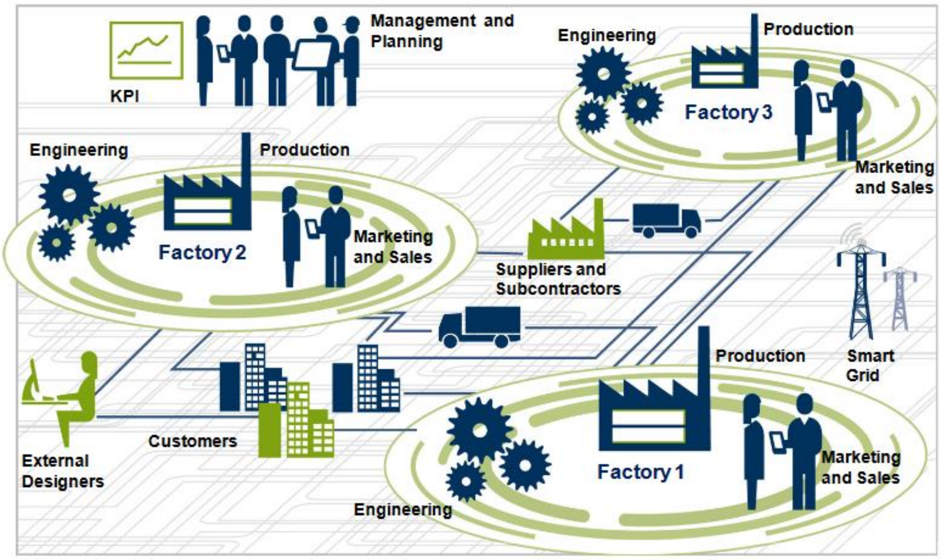

Figure 8 Horizontal value network [29]

Horizontal integration is the new generation of global value chain networks [24]. The concept of horizontal integration supports the horizontal value chain which consists of suppliers, manufacturers, traders and customers [29].

Horizontal integration refers to the integration of various IT systems used in different stages of manufacturing and business planning processes that involve the exchange of material, energy and information within the company and between several companies with an aim to establish an end-to-end solution across the entire value chain [29].

Just as well as the vertical integration, it is enabled by networking via CPPS. The networking includes everything from inbound logistics through warehousing, production, marketing and sales to outbound logistics and downstream services. The networking enables tracking of any part or product and its history which can be accessed at any time. That ensures constant traceability, which is also known as “product memory” [24].

Horizontal integration creates a value-creation network that is real-time optimized and enables transparency, offers a high level of flexibility all the way from the customer through the company to the consumer which enables it to respond more rapidly to problems and faults and facilitates better global optimization [24].The integration of customers and business partners generates the appearance of new business models and new-eco systems.

The concept of horizontal integration of the value chain enables the concept of virtual factories. The virtual factory is an imaginary factory which represents the services of various real factories as an overall service. Virtual factories are greatly powerful because the real factories specialize in heterogeneous manufacturing (products, processes, methods) in terms of flexibility and productivity [48].

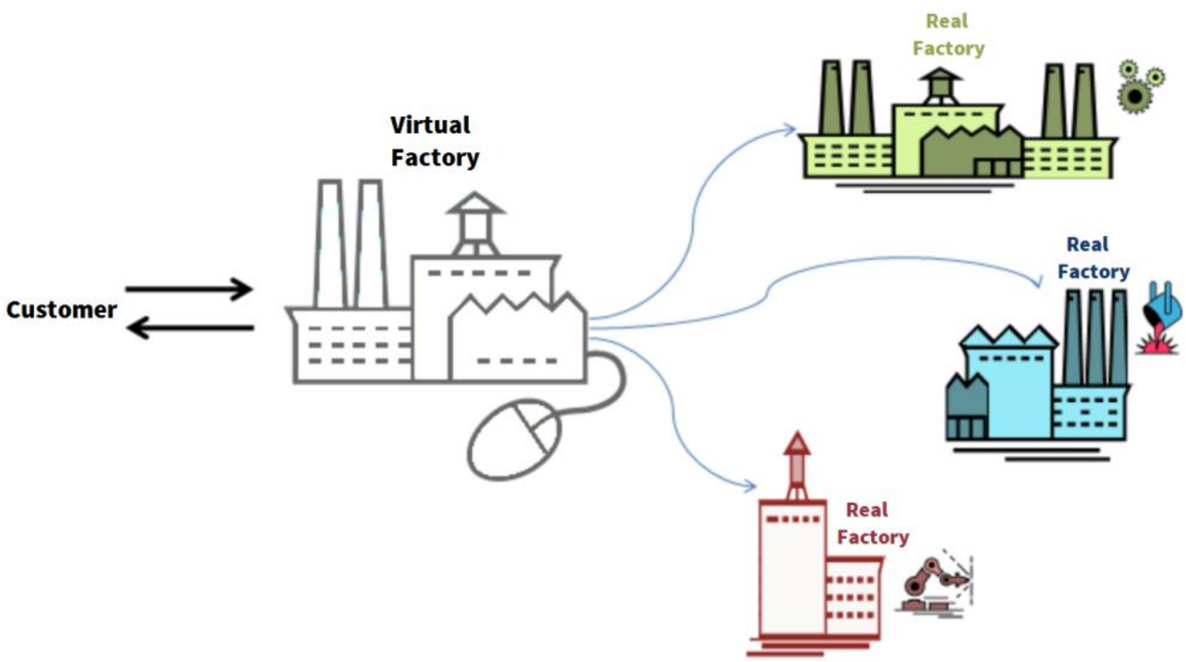

Figure 9 Virtual factory [48]

The virtual factory can assist a production environment by addressing various key issues [49]:

1. Reduction of production times and material waste thanks to the analysis of virtual mock-ups
2. Development of a knowledge repository where people can find stored information in different versions, with both advisory role and support to the generation of new knowledge
3. Improvement of workers efficiency and safety of a collaboration network among people
4. Concurrently working on the same project in different places

Since Industry 4.0 enables the connections of companies, standards will become a key success factor for communication between CPS of various manufacturers [40].

End-to-end digital integration of engineering across the entire value chain

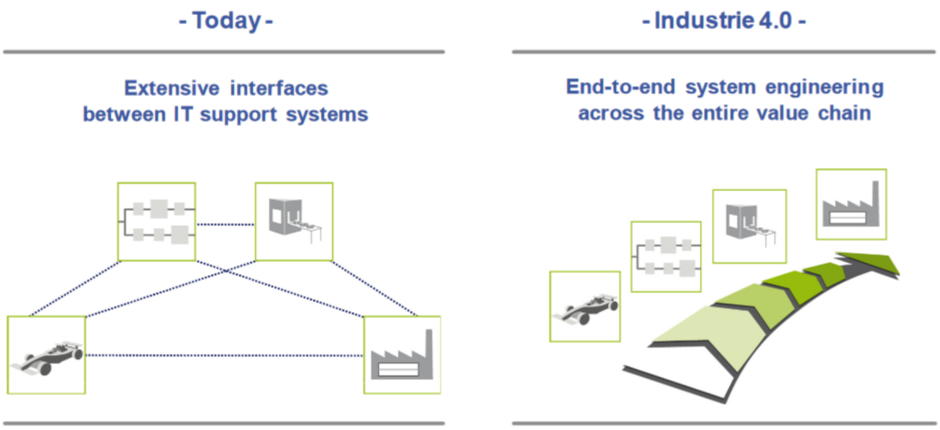

Figure 10 End-to-end system engineering along the entire value chain [29]

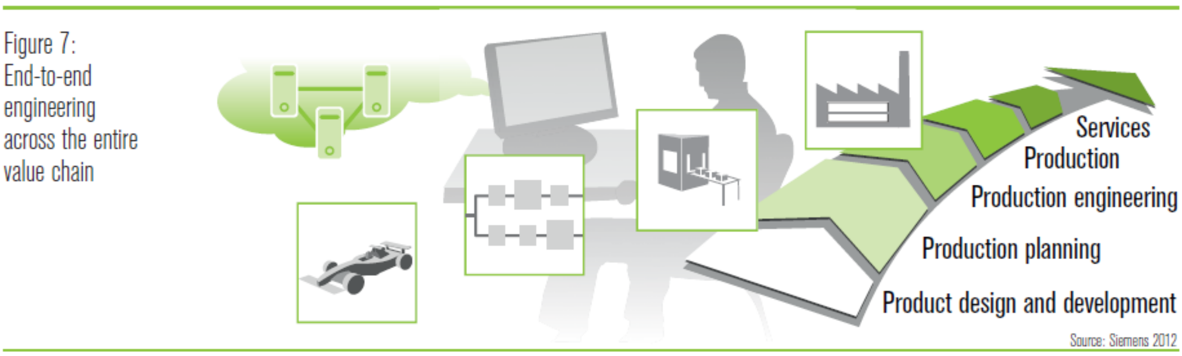

Figure 11 End-to-end digital integration of engineering across the entire value chain [29]

The application of CPS makes it possible to establish a model-based development, which allows the deployment of an end-to-end, modeled, digital methodology. Such methodology covers every aspect from customer requirements to product architecture and manufacturing to the finished product. Such a new approach makes it possible to create customer-specific products. In that way, the customer satisfaction will be higher at lower costs due to the end-to-end integration of the value chain [29].

End-to-end engineering encompasses both the manufacturing process and the manufactured product, achieving seamless convergence of the digital and physical world [29].

"*Industry 4.0 will enable digitalization and virtualization of products and production; connection of virtual and real world, changeability through self-configuration and adaptation; interaction of all parts and processes; hierarchical, continuous and endpoint-oriented communication; adapting the machine to the human being; intelligent networking of processes, products, plants and people* [50]. "

The concept of Industry 4.0 will reshape entire companies and their environment which can be divided in 3 following areas [35]:

1. People

New possibilities for a human-oriented organization of work will arise in the sense of self-organization and autonomy. There will also be new possibilities such as the broadening of the range of employee tasks, increasing employees´ qualifications and abilities, and significantly improving their access to knowledge.

2. Technology

Industry 4.0 systems are easy to understand for the user, they are intuitive to use, support learning and react reliably. The networking and individualization of products and business processes will create complexity, but it will be possible to analyze and find solutions more quickly. The resource efficiency will be continuously planned, implemented, monitored and autonomously optimized. Also, smart products and system components will be addressable and identifiable.

3. Organization

New and established value added networks integrate products, production and services and enable the dynamic variation of the work division. Cooperation and competition will lead to new structures in businesses. There will be opportunities for regional value added activities.

2.4. Digital disruption

As shown, digital technologies can be implemented in many of the areas of businesses and manufacturing processes. Those technologies pose a lot of opportunities for companies, but risks as well.

Digital technologies are accessible, which means that anyone can use them and make an advantage of them. Technical limitations to running a business today are getting smaller and smaller. It is not a question anymore if a company should invest in digital technologies, but how it can make an intelligent use of those technologies to offer more value to its customers is what needs to be answered.

Digitalization offers redesigning and reinventing of products, services and business models. If a company does not figure out how to respond to the changes on the market and does not offer better products or service or new kinds of relationships to their customers, other companies will be able do so. Changes on the market and the competitors which use digital technologies to their advantage can disrupt companies or even industries. Even the world´s leading companies are now threatened by the digital disruptions which change the value proposition of existing products and services by competitors. That is why digital disruption is something every company needs to be aware of in this digital age.

"*Disruption is something that displaces an existing market, industry, or technology and produces something new and more efficient and worthwhile*", so the definition by Clayton Christensen, Harvard Business School professor. "*It is at once destructive and creative* [51]."

He also defined the term "disruptive product" in his book "*The Innovator´s Dilemma"*. "*A disruptive product addresses a market that previously could not be served – a new-market disruption – or it offers a simpler, cheaper or more convenient alternative to an existing product – a low-end disruption* [52]."

Disruptions are unpredictable and they come from unexpected directions. They can be external or internal. External disruptions include changes in the marketplace, geopolitical environment, available technology, etc. which can occur at any time. Internal disruptions include reorganizations, changing management policies, net management, etc. and can lead to an unpredictable result [53].

"*Digital disruption is the change in the competitive environment that results from the use of digital technologies by new market entrants or established competitors in a way that undermines the viability of your product / service portfolio or go-to-market approach*" [54].

Companies need to be aware of the ongoing disruption in their industry. Even if the company is aware of the disruption, in many cases it fails to respond quickly enough to it due to the lack of flexibility. Also, it is not enough for the companies to just be aware of the disruptions taking place in their industry. Companies from completely different industries can also disrupt.

Market and technology experts claim that many companies will not be able to cope with the challenges that await them and Gartner predicts that "digital incompetence" will cause one in four companies worldwide to lose its competitive ranking [55].

Digital disruption becomes an even bigger problem if a company has big proportions because there are a lot of employees who are disconnected to what is happening on the market. In order to detect the signs of disruption in the environment of the company, the company has to take a look outside of its borders.

There are a lot of ways competitors can disrupt. When it comes to the point when the way of doing business has to change because of the changes on the market or changes in customer demand, many established companies defend their products and services against newer technologies if these technologies threaten their existing business model. Such phenomenon is described by Christensen and is called the "innovator´s dilemma" [52].

Companies which are successful and do not make changes in their businesses with new opportunities offered by digital technologies will face the risk of losing their competitiveness on the market. They will get disrupted if they do not change their approach.

It is obvious that digital technologies make every company a potential competitor; even the companies outside the industry can steal customers. In order to keep the customers and survive on the market, digital transformation of the business is a must.

2.5. Digital transformation

Technical advancements and increasing networking pose a challenge to companies through digital disruption. However, they also offer new chances and opportunities in growing the value for customers by creating a meaningful change in their businesses.

Companies have already been exploring how to exploit the benefits of digital technologies for many years. Not to get their business disrupted, companies will need to adjust their businesses through digital transformation which will reshape many industries through the application of digital technologies.

Digital technologies will change every essence of the business which means that companies will need new ways of doing business. Digitalization should only be seen as an enabler and a catalyst for new optimized ways of doing business since new technologies alone cannot make a change or generate any benefit. Only their successful implementation into new organizational forms, products and processes can generate economic growth. According to David L. Rogers, "*digital transformation is not about the updating of technologies of an organization, but about the upgrading of the strategic thinking*" [56]. That is why companies of almost all industries are now challenged to recognize and react to new challenges and to adapt their business models and strategic thinking to the new digital era [57].

Companies can expand their business by impacting products, business processes, sales channels, supply chains; achieve an increase in sales or productivity, create innovations in value creation and novel forms of interaction with customers. Opportunities being made by digital technologies enable companies to reshape or even replace entire business models across all industries [58].

Business models are fundamentally linked with technological innovation. However, the business model construct is essentially separable from technology [59]. To quote Henry Chesbrough: "*A better business model often will beat a better idea or technology*"[60].

Also, the competitiveness on the market is often linked to the ability to quickly adapt business models and companies´ strategies to the changes on the market or in customer demands [61]. That is why the companies need to come up with a company-wide digitalization strategy.

Digitalization strategies come from a business-centric perspective and focus on the transformation of products, processes and organizational aspects owing to new technologies [62].

The figure below, from the survey "*The Future of Work*" shows the biggest drivers behind the need to transform the business. It is shown that the biggest drivers are: improving customer experience, innovation, technology and decision making. Customer is the one who is driving the digital transformation [63].

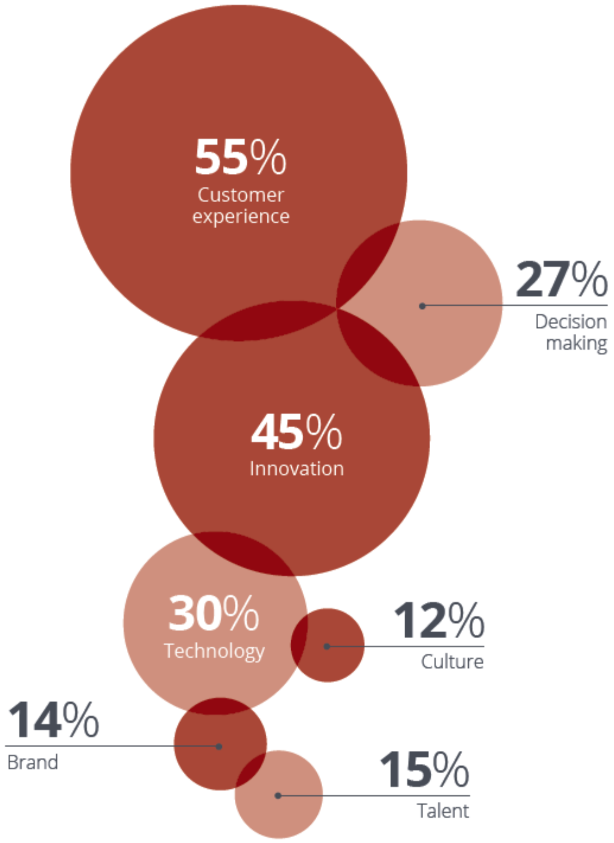

Figure 12 Biggest drivers behind the need to transform the business [63]

David L. Rogers, a globally recognized digital expert, argued that traditional businesses need to rethink 5 domains of their strategy to cope with the changes on the market [56].

Business strategy consists out of company´s coordinated efforts to use its core competencies to gain a competitive advantage. Nowadays, it is no longer enough to define the strategy as the singular exploitation of core competences to maximize gains since the companies need to compete in mature markets with mature digital technologies and they need to simultaneously explore new markets with new technologies [64].

Also, large companies need to stop thinking and acting as if they are a single monolithic institution with one business model but start viewing themselves as portfolios of products and services [64].

There are 2 possible options when it comes to defining the digitalization strategy [65]:

1. To expand the existing business model to include digital elements, especially relating to the product and service portfolio;
2. To set up completely new business models, possibly using existing competences or access to market.

Digitalization strategies usually focus on specific needs of the company and incorporate new business models, digital product and service innovation and process automations.

The domains of the strategy companies need to rethink according to Rogers are the following ones [56]:

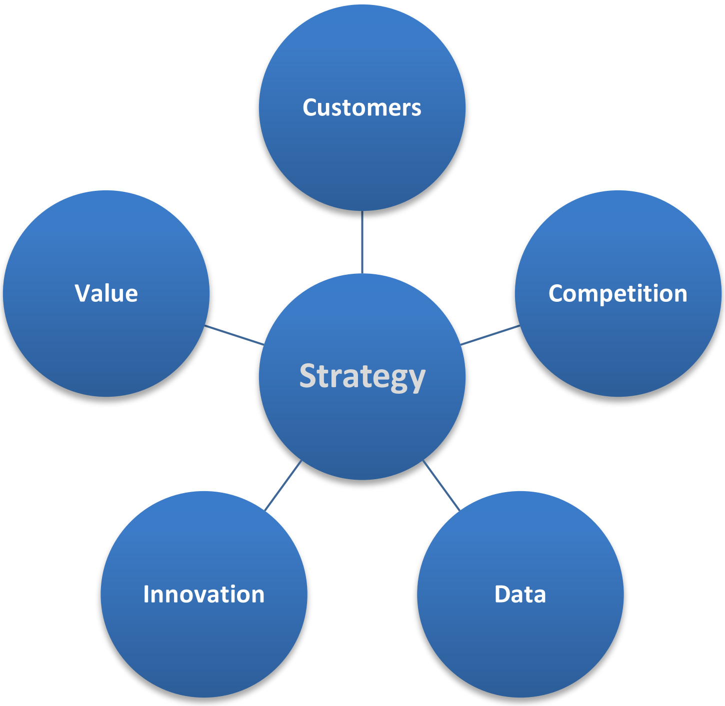

Figure 13 Five domains of a business strategy

1. Customers

If a company wants to attract new customers and keep the existing ones, it has to be ready to offer them a unique customer experience. Traditionally, customers were those who needed to be marketed and persuaded to buy. Companies used to focus on achieving mass production and mass communication for marketing. Nowadays, such approach cannot be used anymore because of the following trends in the customer domain of the strategy [56].

New interactions with customers

Customers of today are people who are very active online and very well-informed. They are also changing their wishes quickly. Furthermore, the customers who come from the generation of "digital natives" expect new types of relationships with the suppliers of the products or services. Before, customers would visit a store and then decide on the product they want to buy. Nowadays, when the customers enter the store, they have already researched relevant features of the product and gathered the product specifications and prices online. It has never been as easy as today to access so much product information for customers. They expect a different experience once they enter the store.

Also, customers nowadays do not even need to go to the store in order to buy a product. Purchases can happen online, on cloud based apps for example. That is the reason why companies need to think about the customer experience online, without face-to-face interaction.

Customers of today and of the future expect personalized, customized, or even individualized, interactions via various channels, both online and offline [66]. Companies need to keep finding ways of creating value for the customers and securing their loyalty for the future which is enabled by new tools that companies can use to interact with their customers in direct ways.

Individualization

Another aspect companies need to consider when thinking about digitalizing their businesses is – individualization. A lot has changed since 1930s, when Henri Ford said “"*You can have any color as long as it´s black*" [67] while talking about the color of the car he offers to his customers. He was not interested in his customers´ wishes and preferences on the color, but he made the color he wanted to make. Nowadays, we are not talking about a market which accepts mass production, not even mass customization, but individualization of products.

Today, customers expect more models and variants. They expect individualized products which meet their specific individual profile and requirements [66]. Companies have to fulfill the customers´ desire for individualized products.

Zero tolerance for quality issues

Customers are the ones who define the acceptance criteria for the quality of products or services they buy. Not everything on the market needs “top quality”, but companies need to take into consideration that customers are changing their acceptation to quality issues.

Quality issues erode customer confidence. Customers have zero tolerance for quality issues and will immediately go to competition if these are encountered [68]. Nowadays, it is easy for the customer to find different providers of products they require if they are not satisfied with the quality. Also, customers of today are even willing to pay a higher price of a product or a service if they strongly believe that they will have no quality issues with such product or service.

Customer integration in business

Customers have evolved from just passive receivers of products or services. They have to be seen as a dynamic customer which can even be integrated in the internal business processes. Companies need to find ways to fulfill the customer requirement of greater participation in business processes.

Also, customer integration communicates a customer-centric mindset as it lets the customer know that they are the center of the company´s activities [70].

Availability on demand

Another trend on the consumer market is that more and more, especially younger people find that the possession of objects is less important to them than their availability and performance which, as already described, is the trigger for the sharing economy. Companies need to find new ways of doing business by offering products or services which can be shared and paid only when used. Companies also need to keep in mind, that the variance of such products is less important since the product has to fit the requirements of a mass of people.

Customer networks

The use of digital technologies changes how customers discover, evaluate, purchase, and use products. Also it changes how the customers share, interact and stay connected with the brand. Today, customers connect to each other and influence each other and in such a way that they shape business reputation [56].

Customers use social media and other channels to comment and rate products or services. Companies need to rethink their traditional ways of marketing and use of social networks, search engines, and other channels to target their customers [56]. They also need to be aware that new potential customers can shape their opinions on top of the online business reputation which can have beneficial or disadvantageous effects on the company.

2. Competition

The domain competition describes how businesses compete and cooperate with other businesses. Traditionally, competition and cooperation were seen as binary opposites. Companies would compete with other companies similar to themselves – companies inside the defined industry, and they would cooperate with supply chain partners [56].

Nowadays, the market is going more and more to the state of "no boundaries". Companies will have to compete with companies similar to themselves but also with companies that look and do business absolutely differently. Those companies can even become the biggest competitors because they offer competing value to the same customer [56].

Digital technologies can create new market participants and influence the value chain of the companies [69]. New market participants cannot be neglected when companies are considering a new business model since they can also disrupt the existing market participants.

Since there are so many challenges outside of the industry, direct rivals need to cooperate due to interdependent business models and mutual challenges [56]. For companies it will play a crucial role how they can collaborate with their rivals.

3. Data

Data generation

Before, data only used to be produced through planned measurements such as customer surveys or during company´s processes and it was mainly used for evaluation, forecasting and decision making [56]. Data used to be expensive and difficult to obtain. The storage space for data used to be small in the past and it was sometimes difficult to make an advantage of the collected data.

Today, as more and more devices get connected, it is possible to gather more data from production to consumption. Data is generated by everyone at any time in unprecedented quantities, from every conversation, interaction, or process inside or outside the business. It is also produced everywhere; from customers in customer survey, social media to within company´s own processes like manufacturing, operations, sales, marketing. Social media, mobile devices and sensors on every object in a company´s supply chain generate unstructured data without planning and such data can increasingly be utilized with new analytical tools [56]. Companies need to find ways to make advantage of data by doing things with data that they have never done before.

4. Innovation

The fourth domain of the strategy that needs to be rethought is innovation. Innovation is the process in which new ideas are developed, tested and brought to the market by businesses [56]. Innovation is seen as a key factor which enables economic growth and competitive advantage.

Traditionally, innovation was managed with a singular focus on the finished product. Market testing was difficult and costly; most decisions on new innovations were based on the analyses and intuition of managers. The cost of failure was high, so avoiding failure was paramount [56].

Today´s conditions on the market make company´s ability to innovate and to respond to the changes on the market quickly more important than ever. The pace of technological developments enables innovations which influence many changes on the market. Companies need to find ways to carry out innovation cycles in a shorter time and carry out cheaper solution.

5. Value

The domain value describes the value a business delivers to its customers – its value proposition. The classic value a business offered to its customers was assumed to be constant and defined by its industry. For example, car companies offer transportation, safety, comfort and status in varying degrees. A successful business used to be the one that had a clear value proposition, a clear degree of market differentiation and focused on executing and delivering the best version of the same value proposition to its customers year after year [56].

Now, in the digital age, delivering the best version of the same value proposition means eventual disruption by competitors. The only right thing to do is the constant evolution of the business, looking to every technology as a way to extend and improve the value proposition to the customers. Companies need to focus on seizing emerging opportunities, divesting from declining sources of advantage and adapting early to stay ahead of the curve of change. Waiting to adapt when change comes will become a matter of necessity [56].

There will be a transformation in each of these five domains due to changes on the market and new possibilities enabled by digital technologies and strategies. Companies will need a new framework for formulating strategies in order to adapt and grow in the digital age [56].

Employee skills

Formulating a new framework for the strategy in order to adapt to the changes is not all companies will need to focus on. "*Changes in industries and business models will affect the quality, skills requirements and day-to-day content of virtually every job and that is what every company needs to take into consideration*. [6]"

Digital technologies will enable new ways of doing work such as telecommuting, co-working, freelancing, virtual teams, and online talent platforms [6]. Digital technologies have the possibility to enhance productivity, transparency, connectivity, team work, make communication easier and increase employee satisfaction and retention.

Digital transformation will expectedly result in an increase in in-demand jobs and an increase in skills requirements. The work-life balance is expected to become more important in almost every industry with the general trend towards flexible ways of working which is identified as one of the biggest drivers of transformation of business models in many industries [6].

New ways of doing work which include the use of digital technologies or automated processes which will replace human work will change the traditional qualifications and specific skills required from employees. Increased automation, connectivity enabled by Internet of Things, use of data for data-based decision making are just a few examples of technologies which will change the way people work. Employees of the future will have to learn how to quickly adapt to changes in their work.

It is not a surprise that the demand for the skills in the future will greatly change since the most in-demand occupations or specialties of today did not even exist ten or five years ago [6].

The figure below shows how many jobs will require new skills in their core skill set in 2020 (the bright blue part of the bar) and how many jobs will remain with the same set of skills in demand over the 2015-2020 period (the dark blue part of the bar).

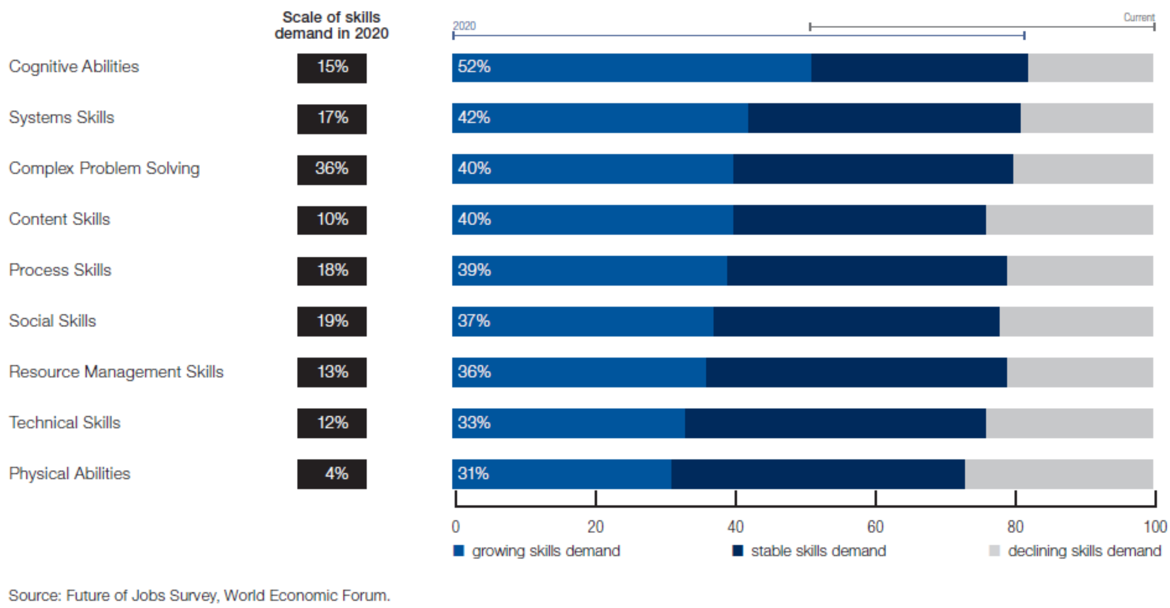

Figure 14 Change in demand for core work-related skills [6]

It is obvious that the main trend with all of the skills listed on the figure is that their demand will grow for many jobs which do not yet include those skills as a part of their core skill set. For example, cognitive abilities will make its way into 52% of all jobs and will remain important in another 30% of the jobs. There will be a growth in demand for system skills, complex problem solving skills, content skills and process skills in about 40% of all jobs. Technical skills and physical abilities, on the other hand, will face a decline in skill demand in about 25% of all jobs.

The Report estimates that, social skills which include persuasion, emotional intelligence and teaching others will be in higher demand overall than narrow technical skills [6]. Those are the skills which separate humans from robots. It is the result of employing more and more robots in processes.

Content skills such as ICT literacy and active learning; cognitive abilities such as creativity and mathematical reasoning; and process skills such as active listening and critical thinking will be a growing part of the core skills requirements for many industries [6].

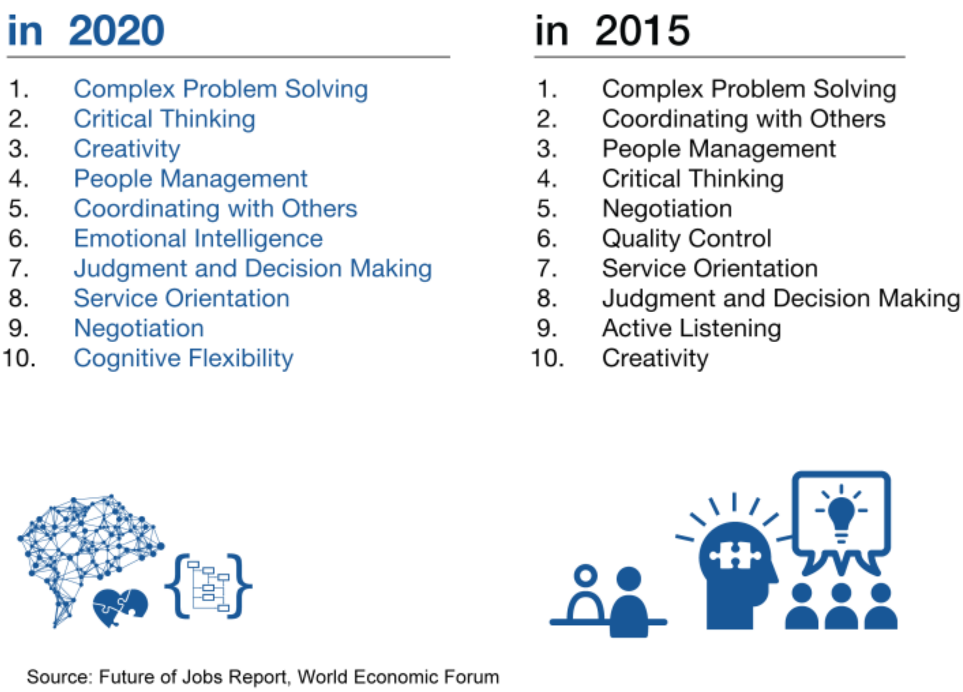

Figure 15 Change in the most important skills from 2015 to 2020 [6]

The Report also generated a Top 10 skill list for 2020 which compared to the Top 10 skills in 2015 shows big differences. As shown on the figure above, a fifth of the skills in the Top 10 list for 2020 are not even essential today according to the estimates in the Report.

Complex problem solving skills will still stay on the top of the demanding skills in 2020. Many other skills such as critical thinking, people management, judgment and decision making, service orientation will not greatly change their position in the Top list.

Creativity will become a much more valuable skill in 2020 with the use of new technologies and new ways of working which change every day work and require such skills. It has moved from the number 10 to the number 3 on the list. It is not a surprise that creativity will gain so much in importance since a lot of processes in the future are expected to become automated. They will be done by robots which will help in doing things faster and easier for people. One thing that robots cannot be taught is creativity.

Skills such as negotiation and cognitive flexibility will not be on the Top 10 list for 2020 anymore since machines will be able to use the data from analyses and also be able to make decisions instead of people. Active listening, one of the core skills of today will disappear completely from the top 10. Emotional intelligence, on the other hand, which is not even in today´s core skill set, will become one of the core skills in 2020.

With the focus on manufacturing industry, which will face yet another increase in automation with the concept of Industry 4.0, it is expected that the employees in manufacturing processes will have more responsibilities related to equipment control and maintenance. Such responsibilities will require problem-solving skills, as well as a broader general understanding of work processes of their company [71].

Another change is that the technical occupations will require creative and interpersonal skills since employees will spend less time with machines, and more time with other colleagues [71].

The changes in demand of skill requirements will definitely result in substantial challenges for recruiting, training and managing talent [6]. The challenges connected with recruiting will be great since only 52 per cent of the surveyed HR managers believe that their companies are well-prepared for the upcoming changes.

In terms of training and managing talent, the Report states that "*the companies can no longer be the passive consumers of fully developed human capital*" but that they have to invest in the training and further education of their workforce [71].

2.6. Closure

After digital disruption, digital transformation and recommendations for the business strategy change have been described, the thesis will now focus on the digitalization-related changes in the automotive industry and on the opportunities of automobile manufacturers to respond to those changes. The example will be given on the digital strategy of the Volkswagen Group.

3. Automotive industry in the digitalization era

The automotive industry is one of the most complex industries as it involves multiple phases such as design, engineering, pricing, manufacturing, distribution, selling, and servicing; and each of these phases consist of numerous complex processes and technologies that have to be fully integrated into one seamless system, ensuring success at enterprise level [72].

There are a lot of megatrends which have a far-reaching impact on automotive industry such as industrialization and urbanization in emerging economies, sustainability regulation and policies, changing demographics as well as consumer preferences and the rise of new technologies [73].

The level of development of the automotive industry is very high since new digital technologies have already impacted and will continue impacting automobile manufacturers. The automotive industry is currently undergoing one of the biggest changes since the invention of the automobile more than 120 years ago [74]. According to the experts from the industry, the automotive industry will face fundamental changes when it comes to the car as the product, as well as the changes in the production of the car.

Old, established companies, as the majority of them in the automotive industry, are usually slow to react to new technologies and to predict the impact new technologies have on their activities and their position on the market.

3.1. Changes in automotive industry

Even though digitalization has changed the automotive industry, the concept of the classic vehicle has still not changed [72]. However, the number of sensors, control devices and software in cars are increasing in order to make driving safer and more comfortable. Since there is an increase of IT being implemented in the cars, tech giants such as Apple or Google will also enter the automotive market [74].

Automobile manufacturers will have to deal with the changes on the market which include increasing customer demands, the complexity of the product and the expanding supplier network. In addition to the market pressure from the existing competitors, new market entrants will also pose a challenge. Automobile manufacturers will have to find ways to meet the ever-increasing demand with adapting to new technologies on an ongoing basis and leveraging those technologies to their advantage.

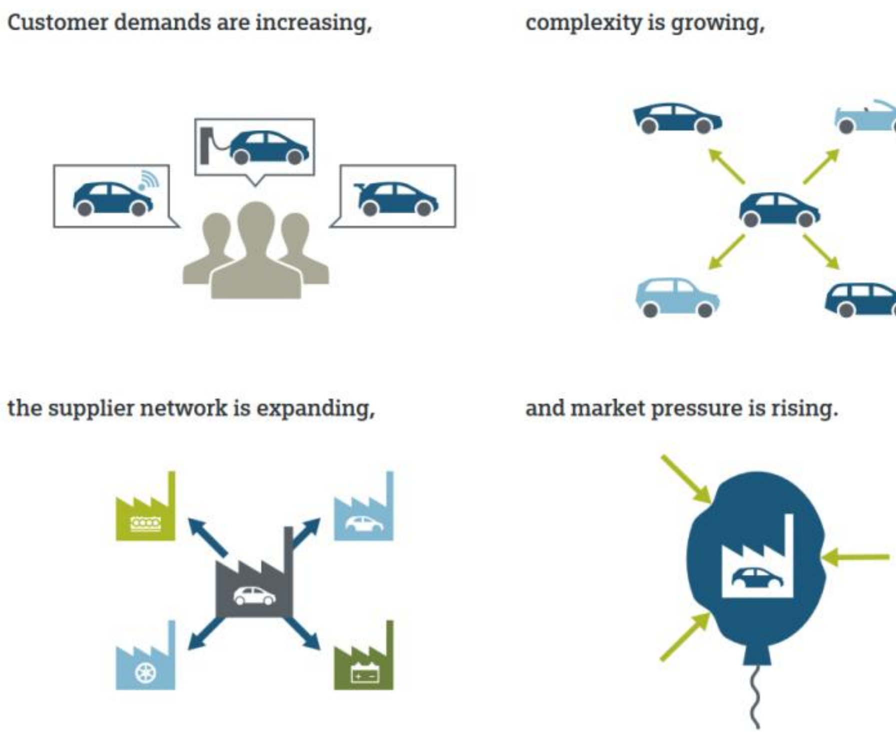

Figure 16 Changes on the market in the automotive industry [75]

Business models, structures, processes, leadership culture and competence requirements of automobile manufacturers and suppliers will be questioned due to the changes on the market in automotive sector [74].

Traditionally, the experience customers expected when buying a car was limited to basic services like extended warranties, service contracts, insurance, etc. – today, they demand for a new set of services [76]. Customers do not only buy a vehicle for transportation. They want an ”experience package” and a highly customized vehicle.

Most industry players and experts agree that there are 4 disruptive megatrends in automotive industry which will reinforce and accelerate one another. Those are: diverse mobility, autonomous driving, electrification and connectivity [73].

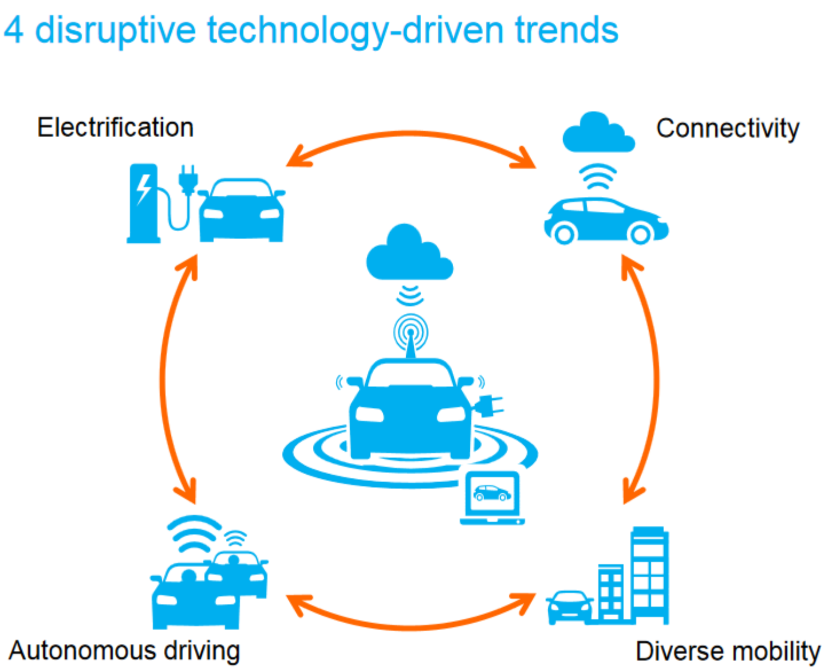

Figure 17 Four disruptive technology-driven trends [73]

3.1.1. Diverse mobility

Consumers are changing their behavior to mobility. Today, it is usual that a person has one car for every trip purpose such as business, leisure, vacation, shopping and commuting to work. In the future, the consumers will be shifting towards different mobility solutions for every of those purposes, as shown on the figure below. There will be a rise of a market or fit-for-purpose mobility solutions [73].

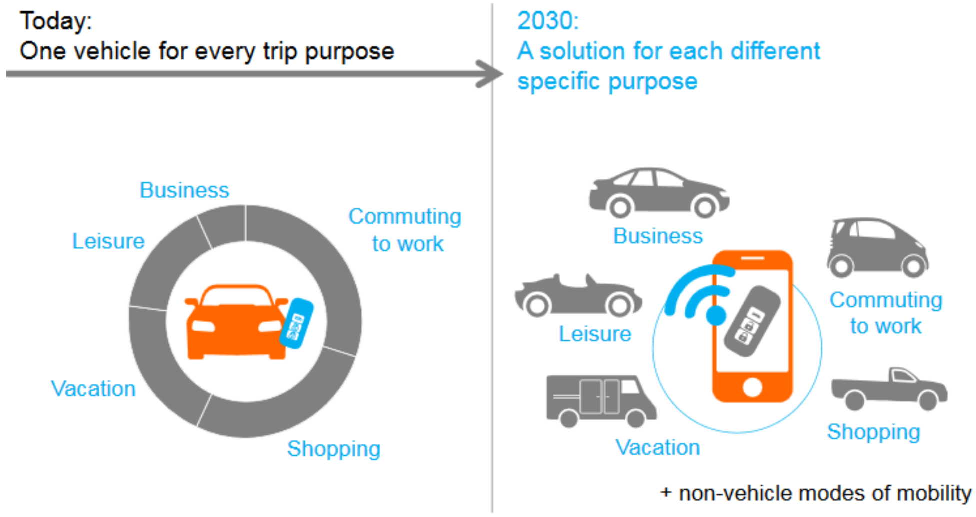

Figure 18 Purpose of vehicles today and in 2030 [73]

One of the mobility solutions which is expected to be on the rise is the car sharing concept. Predictions show that 1 out of 10 cars sold in 2030 will be a shared vehicle.

Already today, car sharing is very popular, especially in larger cities due to the fact that it offers flexibility and positive environmental effects which are concerning more and more people as they keep trying to find a replacement for private car ownership.

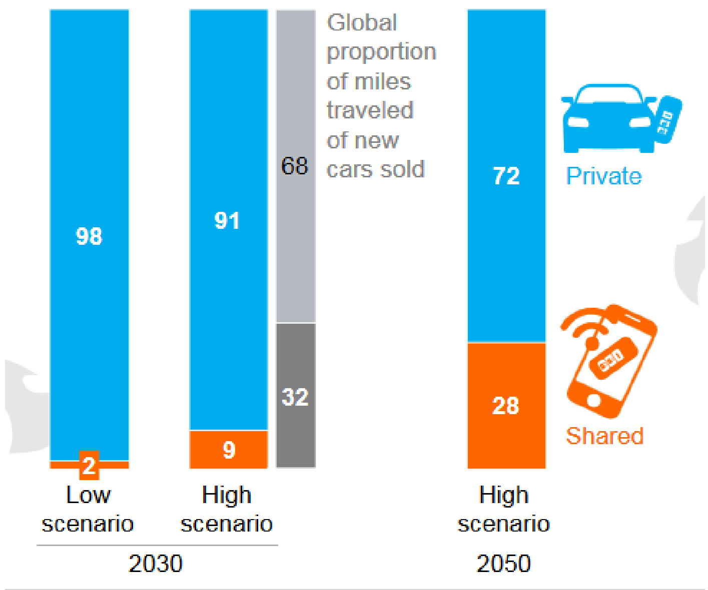

Figure 19 Predictions for the ratio of private and shared cars in 2030 [76]

3.1.2. Autonomous driving

As already mentioned, complete or partly autonomous driving is already possible in cars, trucks, aircraft and boats. The entire automotive industry is aware that this trend has the potential to reshape the whole market.

This technology allows for the car to become a platform for drivers and passengers to use their transit time for personal activities [77]. An interesting fact is that an average passenger spends 50 minutes per day in the car. Also, the average per capita daily private usage of internet is also 50 minutes [78]. Autonomous driving could combine those two together since it would allow all the passengers, including the driver, to spend their time the way they want to during the transit time.

Autonomous driving also addresses the problem of parking searching since the car has the ability to drop off and pick up the passenger on the same location [77].

3.1.3. Electrification

Electrified vehicles are becoming more viable and competitive, but the speed of their adoption will vary greatly at a local level. There are both “push” and “pull” factors for producing electrified vehicles. The push is created by the increase in emission targets regulations leading up to 2030, rising citizen concern for climate change and new and continued electric vehicle subsidies. The pull factor is created by consumers. High-performance electric vehicles demonstrate growth potential in the premium segment. Oil and battery prices change total cost of ownership for mass-market segments. Also, customers show high loyalty of current electric vehicle owners [73].

3.1.4. Connectivity

Connecting cars to the internet is a central trend in the automotive sector. Connectivity in the car is both a logical expectation of the customers and a necessary prerequisite for intelligent vehicles which will be able to drive autonomously. The increasing dominance of software in the car calls for structural adjustments for automobile manufacturers and suppliers since software, IT and internet competences will become an indispensable resource for meaningful differentiation on the market [74].

There are new prerequisites for the differentiation on the market for automobile manufacturers and suppliers and those include software, IT and internet competencies. It will become increasingly difficult to gain competitive advantages with classic approaches [74].

When it comes to switching the car manufacturer and paying a subscription fee for connected car services, both have increased significantly from 2014 to 2015 [73].

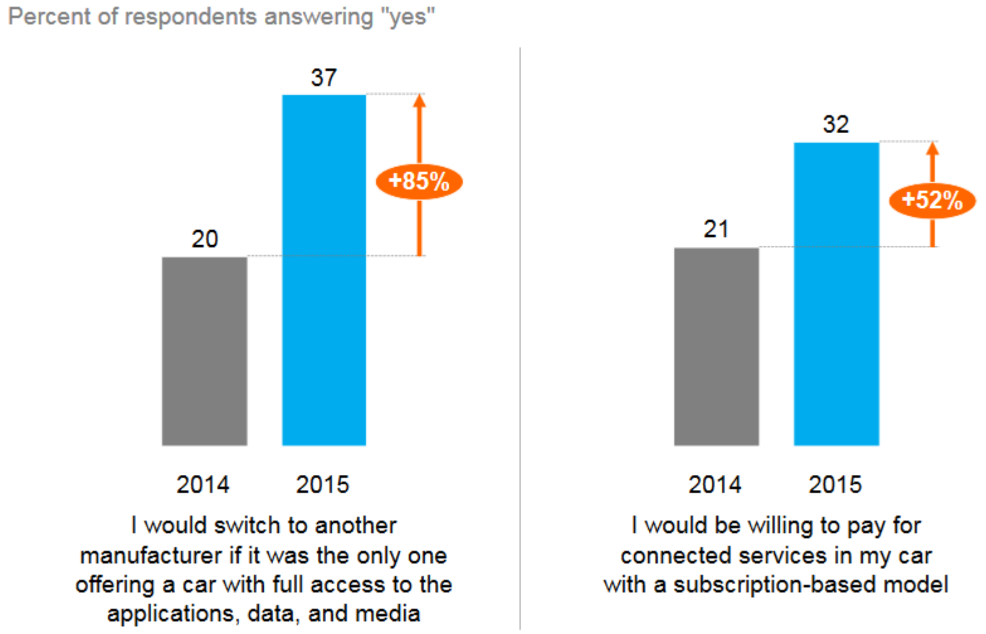

Figure 20 Customer changes in regard to connected services in a car [77]

An automatic, super-efficient connected, self-driving car – always in synchronization with its cloud and the Internet of Things – is being pitched to be the next frontier of electronics post the smart phone revolution [79].

The automotive industry should not be focusing on reinventing the car, but about the reinventing of mobility since cars will become apps on wheels [80].

It is possible to conclude that the new technology-driven trends have are expected to have many benefits which include: less congestion, lower emissions, greater efficiency, lower costs and saved lives [81].

Since the trends in automotive industry have already been identified as disruptive and will fundamentally reshape the entire industry, energy companies, insurers, health care, government funding and more; automotive companies need to define their digitalization strategies, as already discussed before, in order to gain a competitive advantage.

Even though experts advise companies to focus on building digital business models focusing on new mobility solution, digitalizing products and services in the established portfolio, digitalizing supply chains and recognizing the importance of digital business operations, there are still many companies that do not have a digitalization strategy. More specifically, 40% of Original Equipment Manufacturers (OEMs) did not have one in 2015 as shown on the figure below [65].

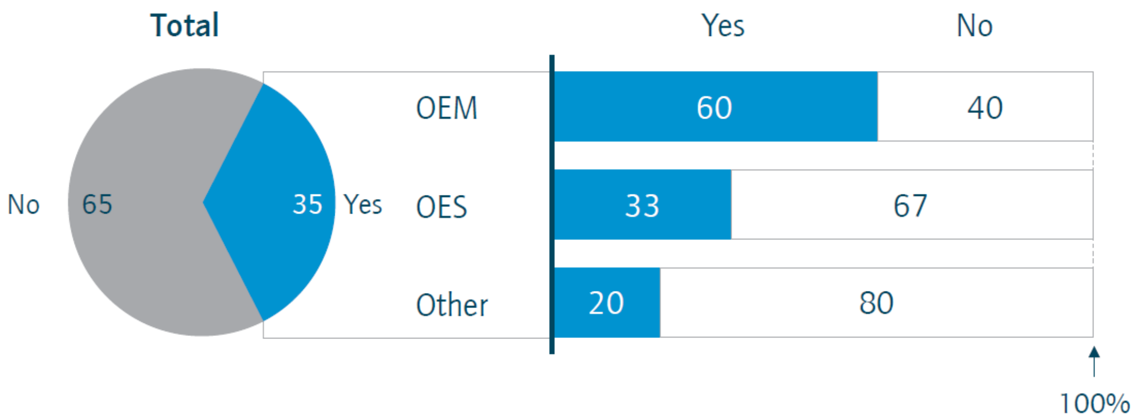

Figure 21 Companies with an existing digitalization strategy in 2015, figures in percent [65]

3.2. Closure

After the biggest technology-driven megatrends in the automotive industry have been discussed, the thesis will now focus on the Volkswagen Group, and its vision of answering to the changes in the industry with a new transformational strategy.

4. Volkswagen in the digitalization era

4.1. Volkswagen

Volkswagen AG, as many other companies, is challenged today by the changes influencing the automotive industry and car manufacturers. Volkswagen AG has defined a strategy for targeting digitalization and mobility solutions according to specific needs of the company which will now be given as an example of a digitalization strategy.

The Volkswagen Group or “Volkswagen Aktiengesellschaft”, shortly “VW AG” is a German automotive company with the headquarters in Wolfsburg, Lower Saxony, Germany. The company was founded in Berlin, Germany in 1937 and today operates in 120 production plants in 20 European countries and a further 11 in the Americas, Asia and Africa. With 600,000 employees in total, the Volkswagen Group is one of the largest employers in the world [82].

The company operates through following segments: Passenger Cars, Commercial Vehicles, Power Engineering, and Financial Services [82]. The Volkswagen Group comprises 12 brands: Volkswagen Passenger Cars, Audi, SEAT, ŠKODA, Bentley, Bugatti, Lamborghini, Porsche, Ducati, Volkswagen Commercial Vehicles, Scania and MAN [82].

The key people in the company are Hans Dieter Pötsch, Chairman of the Supervisory Board, and Matthias Müller, Chairman of the Board of Management.

The Volkswagen Group is one of the world´s leading manufacturers of automobiles and commercial vehicles and the largest carmaker in Europe [82].

	Jan-Dec 2016	Jan-Dec 2015	YoY
Volkswagen	10,312,400	9,930,500	3.8%
TOYOTA	10,213,486	10,083,783	1.3%
General Motors	9,574,771	9,800,000	-3.1%

Source: Company data. GM, VW: Deliveries. Toyota: Production. Blue: Estimate

Figure 22 Cars produced by the world´s largest car manufacturers [83]

Global car manufacturers are ranked on the amount of cars produced; not on the amount of cars sold. The ranking is done by OICA (International Organization of Motor Vehicle Manufacturers). The figure above shows the comparison of cars produced for 2016 and 2015 for the world´s biggest car manufacturers: Volkswagen, Toyota and General Motors. In 2016 The Volkswagen Group made its way to be the world´s largest car manufacturer with 10,312,400 cars produced [83].

4.1.1. Volkswagen and the changes in automotive industry

There are major changes in the automotive industry, as already mentioned before. The Volkswagen Group recognizes the changes in the industry such as technological megatrends which are questioning business models partly because the customer needs are changing, tougher competition on the market, shorter innovation cycles and challenges in operating environment in terms of stricter emissions standards and greater volatility on global procurement and sales market [84].

The Volkswagen Group also recognizes which are the major trends concerning mobility and the concept of the vehicle. Those trends are shown on the figure below.

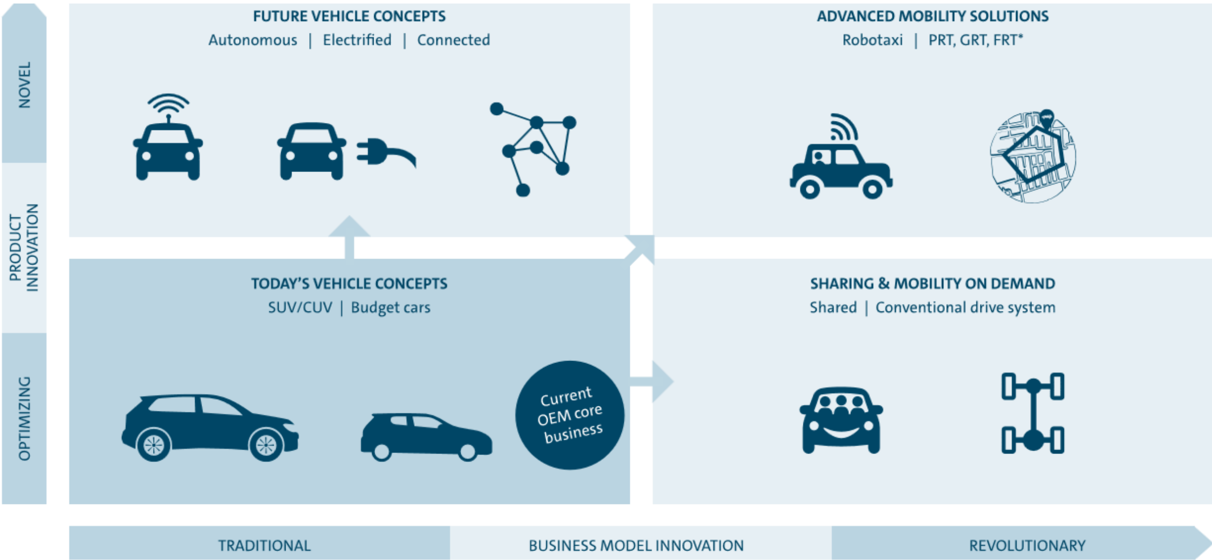

Figure 23 Changes in the automotive industry recognized by Volkswagen [85]

The automotive industry is changing from today´s vehicle concepts to new concepts which include autonomous, electrified and connected vehicles. The concept of the vehicle is also being innovated with advanced mobility solutions and revolutionized by vehicle sharing and mobility on demand.

The Volkswagen Group also recognizes the revolutionary impact the external factors will have on the Group. Those are [86]:

1. Technological megatrends which impact customer needs and business models in a way that current business models are questioned
2. Stronger competition from old and new competitors
3. Higher capital requirements triggered by the need to build up new core competencies and ever shorter innovation cycles to make a more efficient use of the resources and become more agile in decision-making and in action
4. More complex environment as a result of stricter emissions legislation and greater market volatility

4.1.2. The Volkswagen Group – "TOGETHER – Strategy 2025"

There are revolutionary changes in the automotive industry as already described. Digital technologies are bringing new possibilities which can change the products, services, business models and the market which will in the future include an even stronger competition and new customer requirements. That is the reason why the Volkswagen Group has adopted a new strategy – in order to answer to those changes with the goal of becoming a globally leading provider of sustainable mobility.

The new program was adopted in June 16, 2016 in Wolfsburg under the name "TOGETHER – Strategy 2025". More than 250 experts from all parts of the Company have worked on developing the strategy in order to complete the goal by fulfilling the missions of offering tailor-made mobility solutions to their customers, serving the customers´ diverse needs with a portfolio of strong brands, assuming responsibility regarding the environment safety and social issues, acting with integrity and building on reliability, quality and passion as foundation for their work [87].

In such a way the Group would achieve sustainable growth by being an excellent employer, having excited customers, achieving competitive profitability and being a role model for environment, safety and integrity [88].

Matthias Müller, the Chairman of the Board of Management, said that "*the Volkswagen of the future will inspire its customers with fascinating vehicles, financial services tailored to demand, and smart mobility solutions. We will be a technology leader and role model when it comes to environment, safety and integrity. The Group will achieve competitive profitability, and so remain, both, an attractive investment and an excellent, reliable and secure employer. In short, Volkswagen will be an enterprise we can all be proud of.* [89]"

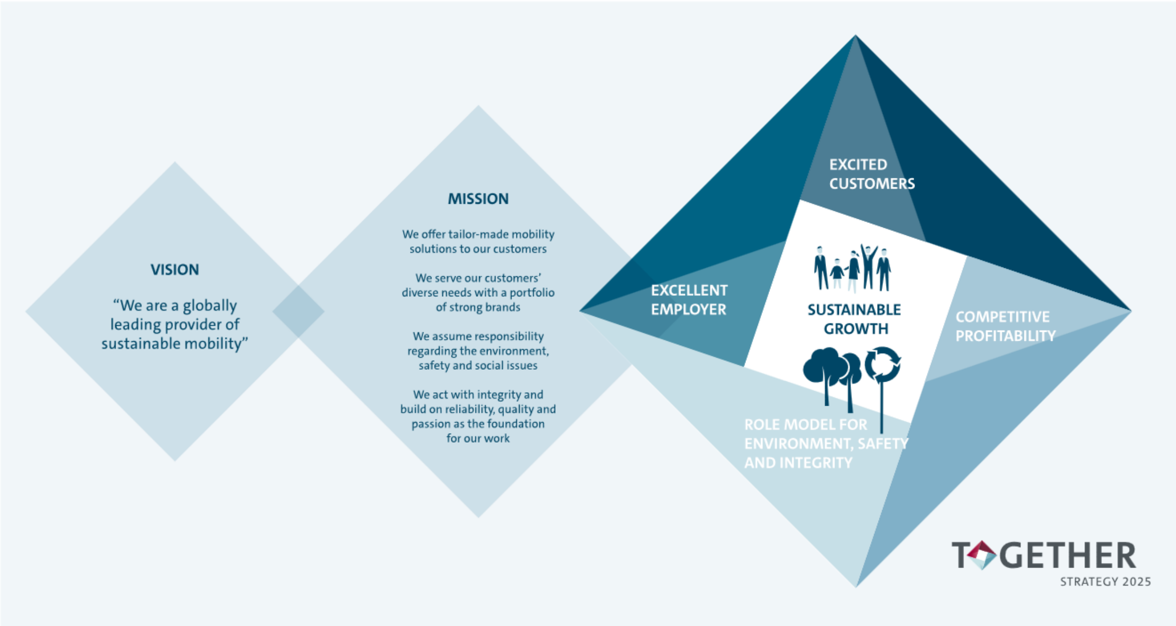

Figure 24 Mission and vision of the „TOGETHER - Strategy 2025“ [85]

CEO Matthias Müller also stated the following: "*Our future program "TOGETHER – Strategy 2025" will make the Volkswagen Group more focused, efficient, innovative, customer-driven and sustainable – and systematically geared to generating profitable growth. We aim to create lasting value for all our stakeholders. This can only be achieved together – with our employees, with and for our customers, shareholders and business partners – while being fully aware of our responsibility toward society and the environment*. [86]"

Figure 25 The mission of the „TOGETHER - Strategy 2025“ [86]

The Group plans to achieve its targets by comprehensively transforming the core automotive business, rapidly establishing a new mobility solutions business, significantly increasing efficiency as well as strengthening innovation power and entrepreneurial mindset and approach in the Company [88].

The Volkswagen Group needs to achieve all of its targets in order to reach the central, overarching goal: sustainable growth, for the stakeholders and together with them [84].

There are four pillars of the strategy for the growth of the Group as shown on the figure below [88]:

Figure 26 Four main building blocks of the „TOGETHER Strategy 2025“ [86]

Each of those pillars is combined with corresponding key strategic initiatives on the Group level as it follows [88]:

- **Transform core business**

  Initiatives in order to grow profitability:

  1. **Sharpen positioning of brands** – the Group and brands will define more precisely than before which growing segments and regions they want to service

2. **Develop winning vehicle and drivetrain portfolio** – that continues to ensure the sustained success under altered market conditions
3. **Streamline modular architectures** – to make better and more disciplined use of their benefits
4. **Partner with regional players to win in economy segment** – by launching a compelling offering in the booming economy segment - Asia

Initiatives to develop strategic capabilities:

5. **Develop self-driving system for autonomous vehicles and artificial intelligence in-house** – those will become the core technologies at Volkswagen
6. **Develop battery technology as new core competency**
7. **Develop best-in class user experience across brands and customer touchpoints –** by building three Volkswagen Group Future Centers around the world where designers and digitalization experts will work on the automobile of the future while making optimum use of the latest technologies

Initiatives to enhance entrepreneurial spirit:

8. **Implement model line organization** – aiming at enhancing entrepreneur the entrepreneurial spirit
9. **Realign "Components" business organization** – aiming at enhancing entrepreneur the entrepreneurial spirit

- **Build mobility solutions –** the second pillar is related to the new core product - mobility

  Initiatives related to the new core product – mobility:

  10. **Build mobility solutions business**
  11. **Develop and expand attractive and profitable smart mobility offering**

- **Secure funding**

  Initiatives:

  12. **Improve operational excellence**

13. **Optimize business portfolio** – securing the finance for the investments in future technologies

- **Strengthen innovation power**

  Initiatives:

14. **Drive digital transformation** – refers firstly to aspects such as Industry 4.0 in the factories or digitalization in sales; secondly aiming for a further sharp increase in the rate of development across all customer-oriented digital applications
15. **Create organization 4.0** – refers to openness and partnership in day-to-day work, but also clear goals and responsibilities backed by a modern, attractive work organization.

All of those initiatives are about harnessing opportunities which result from technological megatrends in the automotive industry. With the "TOGETHER – Strategy 2025" the Volkswagen Group will go through an evolution from car manufacturer into a world-leading provider of sustainable mobility [88].

Also, the Volkswagen Group highlights that product innovations and new business models are interconnected and evolve concurrently. "*Optimization of the conventional business runs parallel to the creation of new business models in areas such as mobility services*. [86]"

In order to ensure the successful transformation of the core business and setting up new "mobility" business, innovation capability will become more important. The Volkswagen Group plans to drive forward digitalization in all areas and functions which will be accomplished through the: digital user experience, digital products and services, smart mobility, digital customer and retail, Industry 4.0 and Business 4.0 [89].

Strategy financing

Transformational efforts, such as the transformational strategy of the Volkswagen Group typically require significant investments. CEO Matthias Müller expects that investments in these future topics will be in the double-digit billion range which will require the reduction of expenses in many areas.

As the figure from the survey “The Future of Work” shows, the main barrier to forming a transformation strategy is not having enough funding. 39% of companies stated that it was the main obstacle for them when willing to form a robust transformation strategy [63].

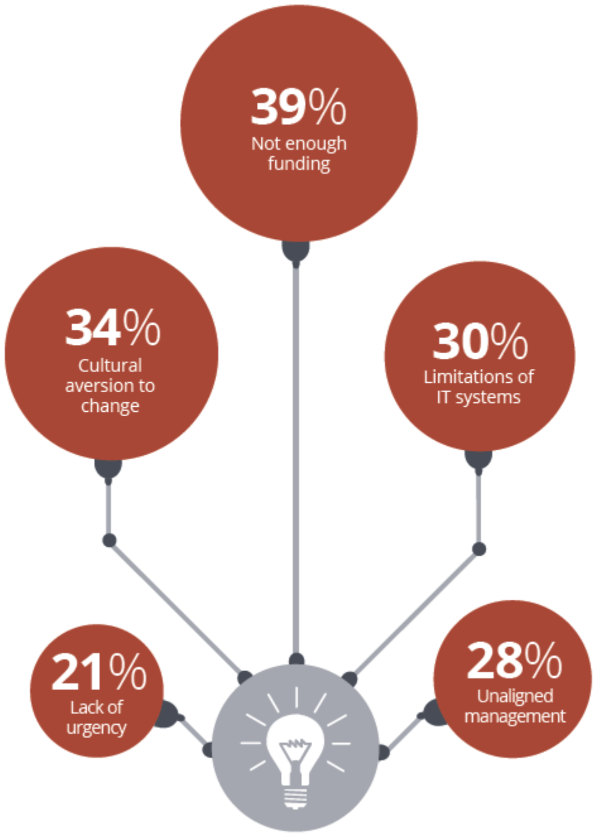

Figure 27 Main barriers to forming a robust transformation strategy [63]

The Volkswagen Group has strong operating profitability. However, there is not enough funding to cover everything. CEO Müller stated that the best way to generate extra funds is by boosting efficiency as there is an ample scope for it in virtually every business unit [84].

4.2. Closure

The transformational strategy of the Volkswagen Group has now been described and it has been highlighted that it will require a lot of funding. One source of the funding will come from improving operational excellence, as one of the initiatives, which will now be described.

5. Operational excellence

Since funding for the transformational strategy of the Volkswagen Group has to be generated through boosting efficiency, “Improving operational excellence” is one of the 2 initiatives on Group level in order to secure the funding, along with “Optimizing business portfolio”. Operational excellence in the Group will have to ensure the funding of the strategy by improving processes across all divisions and functions and throughout the whole value chain from product development through sourcing and production to distribution [88].

Operational excellence (OpEx) is “an opportunity-driven improvement program that identifies opportunities to safely and sustainably increase business value, reduce risk and lost opportunity in a value prioritized sequence” [90]. Operational excellence, in the broadest sense, involves continuous improvements in order to achieve a competitive advantage and maximize the value for the customer and their own financial benefits [91]. It is one of the most important drivers for business success as it focuses on executing efficient processes across the whole value stream since it is a way of looking at the business as a whole rather than dealing with the individual parts of business separately.

Operational excellence is made up of 4 main categories [92]:

- Strategy deployment and execution
- Structured performance management
- High performance work teams
- Optimal process excellence

Figure 28 Operational Excellence

Operational excellence is about the need of organizations to provide the best product or service at the lowest cost possible. Methods used together in order to achieve operational excellence, also referred to as the “Operational Excellence House”, often include quality methods, six sigma and lean manufacturing [92].

5.1. Quality methods

There are many quality methods which pursue operational excellence. One of the quality methods widely used is the Total Quality Management (TQM). The creation of the Total Quality Management philosophy is generally attributed to Dr. W. Edward Deming. TQM is s management approach which aims at long-term success through customer satisfaction.

The word “total” in the name means that the focus of the quality management is not only constraint on shop floor management, but also on all other areas and the environment. It focuses on eliminating waste from the supply chain [93].

TQM based on the so-called Deming cycle or also called PDSA (Plan-Do-Study-Act) cycle which is a systematic series of steps for gaining valuable learning and knowledge for the continual improvement of a product or process.

The PDSA cycle consists of [94]:

Figure 29 Plan – Do – Study – Act Cycle

1. Plan

The "Plan" step involves recognizing an opportunity for improvement and identifying the desired change that wants to be implemented. In other words it involves setting a target or purpose, formulating a theory, defining success metrics and putting a plan into action.

2. Do

In the "Do" step the components of the plan are implemented, tested on a small scale. This step also includes the collection of data which will be studied later.

3. Study

In this step the outcomes are monitored to test the validity of the plan. The results of the previous step are compared with predictions in order to find signs of progress and success, or problems and areas for improvement.

4. Act

The last step, "Act", integrates the lessons learned in the entire process, which can be used to adjust the target, change methods or even reformulate a theory altogether.

The 4 steps are repeated over and over as a part of never-ending cycle of continuous improvement.

The PDSA cycle is the foundation for various improvement activities which include:

- Customer delight
- Reducing development cycle times
- Just-in-Time / Demand Flow Manufacturing
- Improvement Teams
- Reducing Product and Service Costs
- Defect prevention
- Management training on improvement activities

With every cycle, the PDSA makes it possible to create a better product or a service for the customer. The essence of TQM is not controlling quality through inspection but to build quality through design and continuous improvement [93].

5.2. Six sigma

The Six Sigma approach consists of tools and practices that help organizations improve the capability of their business processes. Six Sigma is a registered trademark of Motorola Inc. in the USA who first pioneered Six Sigma methods.

Motorola defines Six Sigma as [95]:

- a metric,
- a methodology,
- a management system.

According to Motorola, "*...at the heart of the methodology is the DMAIC model for process improvement*".

DMAIC is commonly used by Six Sigma project teams and is an acronym for [95]:

- Define opportunity
- Measure performance
- Analyze opportunity
- Improve performance
- Control performance

Figure 30 DMAIC model

Most of the tools and techniques used with Six Sigma are already tested tools and practices which have been available for many years, but Six Sigma organizes them into a more disciplined, focused and clear methodology [93].

The Six Sigma approach is an approach which gives results quickly and can enable an increase in performance and a decrease in process variation which leads to defect reduction and improvements in profits, employee morale and quality of products or services.

Some of the tools Six Sigma uses are statistical process control (SPC), control charts, failure model and effects analysis and process mapping.

In comparison to TQM, Six Sigma uses a “project based approach” wherein a project charter is defined with a clear cut estimation of the realization period as well as the financial gains. Another difference is that Six Sigma includes heavy use of mathematical techniques and analysis. The mathematical techniques are central to Six Sigma´s problem solving steps [93].

5.3. Lean manufacturing

Since lean manufacturing is a production approach derived from the Toyota Production System, first the Toyota Production System will be described.

5.3.1. Toyota Production System

The Toyota Production System (TPS), developed by Toyota Motor Corporation, is the most well known and most studied production system. The foundation of the Toyota Motor Company dates back to 1918 when Sakichi Toyoda established the company.

The Toyota Production System is the practical expression of Toyota´s people and customer-oriented philosophy to provide best quality, lowest cost, and shortest lead time through the elimination of waste. TPS became widely recognized with the publication of “*The Machine That Changed the World*” by J.P.Womack, D.T. Jones and D.Ross in 1990. The book describes the research conducted by International Motor Vehicle Program at MIT which is one of the most comprehensive studies describing the automotive industry and lean manufacturing compared to the Western industry. The research found that TPS was much more effective and efficient than traditional mass production.

TPS is often referred to as a “lean manufacturing system” or “Just-in-Time (JIT) system” since the system is grounded on two main conceptual pillars: Just-in-Time and jidoka as on the figure below.

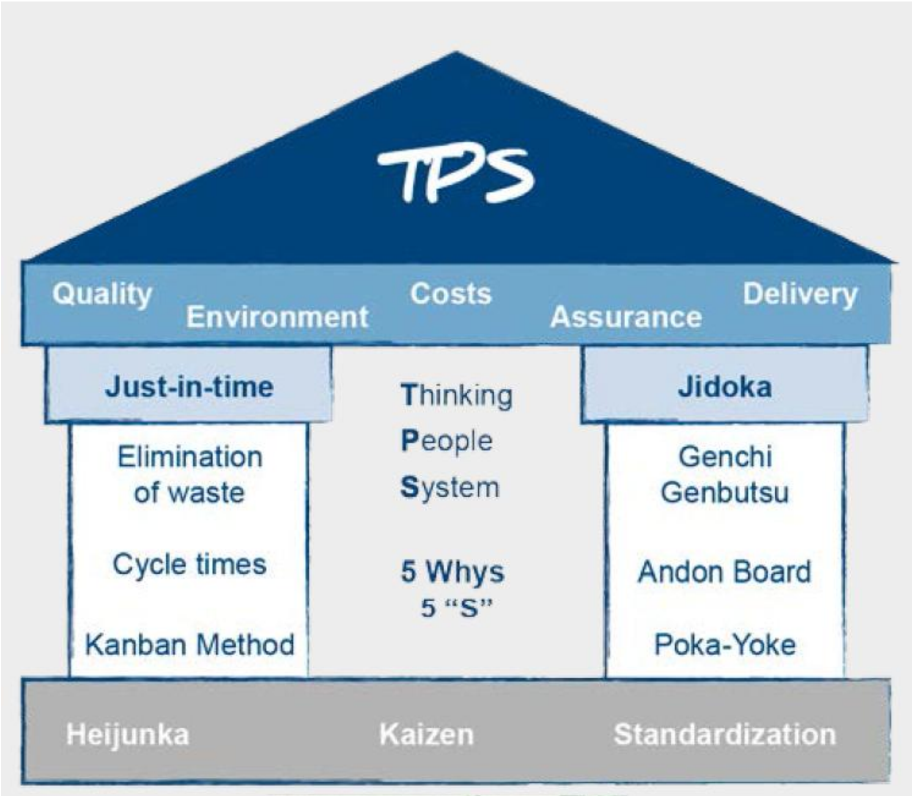

Figure 31 Toyota Production System „House“ [96]

5.3.1.1. Jidoka

Jidoka can be translated to English as intelligent automation or automation with a human touch. It is a quality control process and means that the machine is operating independently under the human supervision and when a problem occurs, the equipment stops immediately, preventing defective products from being produced [97].

Jidoka was developed to eliminate/reduce:

- Overproduction of goods
- Wasted machine time during manufacturing
- Wasted time during transport of defected parts from one place to another
- Wasted time for re-processing of defected parts
- Waste of inventory

There are benefits brought by jidoka in following domains: people, machines, quality and problem solving. Automation made work easier, but people still needed to monitor machines. With jidoka productivity increases because people can operate in several processes at the same time. Machines do not operate until the end of the cycle or until the “stop” button is pressed, but they can detect an error and stop automatically. In this way, jidoka prevents defect parts and breakdown of machines [98].

5.3.1.2. Just-in-Time

Just-in-Time (JIT) is a method of producing and delivering just what is needed, just when it is needed and just in the needed amount. The method aims at producing just the required goods, not taking into account the forecast. In such way, the company will fulfill the market requirements without any waste. Such approach was strongly different from the Western approach to production.

JIT approach relies on heijunka as a foundation. Heijunka translated to English means “leveling” and it refers to, “leveling the type and quantity of production over a fixed period of time”. It helps organizations meet demand while reducing waste in production and interpersonal processes. Leveling the production means being able to efficiently meet customer demands while avoiding batching which then results in minimum inventories, capital costs, manpower, and production lead time through the whole value stream [99].

Leveling the production also enables it to respond to customers´ demand more effectively while avoiding large lots, reducing stock, cost of capital, workforce, and lead time along the entire value stream [99].

There are two main types of leveling based on heijunka:

1. The leveling of production volume,
2. The leveling of the production mix.

JIT is comprised of three operating elements [99]:

1. The Pull system – which means to produce the exact amount that is needed for the next operation in the process, only then when the customer requires it
2. Takt time – measure the available time to produce parts out of customer demand
3. Continuous flow – which means to eliminate all the steps in production which create disruption, delay or destruction and to create the steps which have no negative effects

JIT aims to completely eliminate all types of waste to achieve the best possible quality, lowest possible costs and use of resources, and the shortest possible production and delivery lead times.

5.3.2. Lean definition

The term "lean" was first mentioned in the book "*The Machine That Changed the World*". The term was coined because it was the term to describe the Japanese successful automobile production which, in comparison to mass production, needed less of everything: "*...half the human effort in the factory, half the manufacturing space, half the investment in tools, half the engineering hours to develop a new product in half the time. Also, it requires keeping far less than half of the inventory on site, results in many fewer defects, and produces a greater and ever growing variety or products* [100]".

5.3.3. Lean manufacturing definition

Womack and Jones gave the name to this new production philosophy which was initially focused on the automotive industry but was then shown applicable to other industries. They defined the term lean manufacturing as a "*happy combination of craftsman quality and low cost of mass production. No defects and low costs, this is the winning combination of the Japanes*e" [100].

The Lean Enterprise Institute defines lean as "*the philosophy to maximize customer value while minimizing waste; simply, lean means creating more value for customers using fewer resources"* [101].

By implementing lean manufacturing, *Toyota Motor Corporation* showed an increase in productivity and a decrease in waste by focusing on the strict integration of humans in the production process, on continuous improvement and on value adding activities. The basic idea behind lean is that the organization should be focused on the most effective ways of producing value for their customers.

Lean´s simplicity and up to a 25 per cent increase in productivity are some of the reasons why lean manufacturing has become so popular among manufacturing companies [102]. As Toyota Motor Corporation had shown how powerful the lean tools were, many western companies attempted to implement lean manufacturing as well and it became the key approach since its broader appearance in 1990s. Lean manufacturing was implemented by industries such as: electric and electronics, automotive, auto and machinery, wood, ceramic and machine tool industry. Those industries have implemented lean in their own suitable way and lean significantly changed the market and the way companies do their business [103].

The success of lean manufacturing is accomplished through teamwork, communication, efficient use of resources and continuous improvement. Lean does not only cut the costs but also achieves profit levels equal to those of mass production with volumes lower by one-fourth. Lean also achieves the production of products/services with better quality, since quality defects characterizing Taylor-style production are reduced by two-thirds in lean production [100].

5.3.4. Lean principles

Womack and Jones also defined the approach towards lean processes with waste elimination. The approach consists of 5 principles of lean manufacturing. Those principles are [104]:

1. Definition of value
2. Identification of the value stream
3. Lean flow of the stream
4. Client-pulled flow
5. Perfection

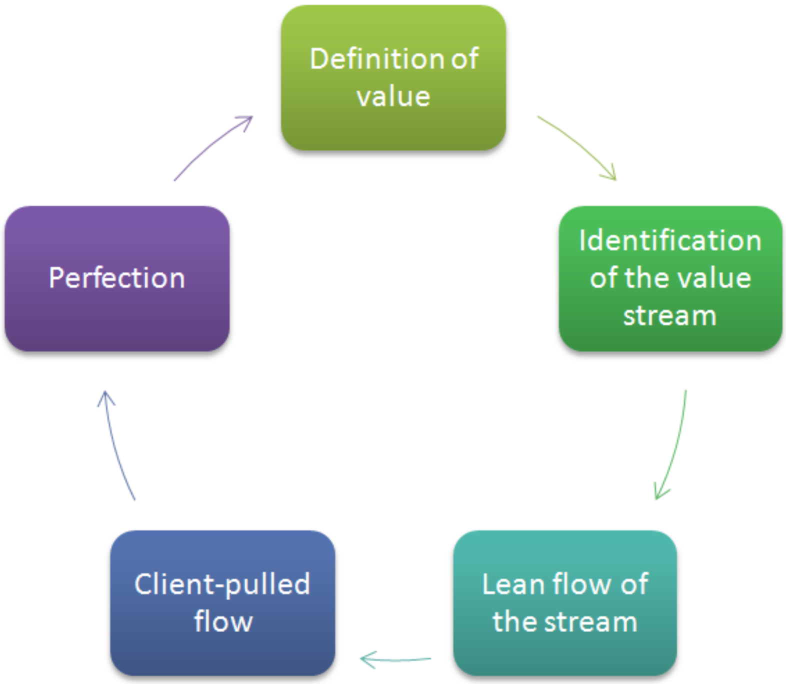

Figure 32 Five lean principles

1. Definition of value

Womack and Jones define value as a "*capability provided to a customer at the right time at appropriate prices, as defined in each case by the customer* [104]" which means that value is the focus and the starting point of lean thinking and that the company needs to specify the value as perceived by the customer or in other words define the value a product / service has for the customer. The company needs to define how much money the customer is willing to pay for their product / service in order to produce according to customer´s requirements.

The core idea of lean is to avoid waste, or in other words, to avoid the non-value-added activities in any process. The customers are not willing to pay for the activities such as waiting, transporting, re-processing, moving, etc. because those activities do not bring value to them and they are the ones who define the value. This is why the value of the product or the service should not be defined from the company´s point of view, but from the customer´s point of view.

2. Identification of the value stream

Womack and Jones defined the value stream as "*specific activities required to design, order, and provide a specific product, from concept to launch, order to delivery, and raw materials into the hands of the customers* [104]".

The value stream consists out of all processes and activities the product has to go through and if all those processes and activities are done correctly and in the right order, they produce the product or service that the customer values. The identification and the analysis of the value stream have to be done in order to separate the value-adding activities from the non-value adding activities.

A lean organization traces and manages all the activities in the organization that deliver value wherever they are and whichever department they are in [106]. Companies need to focus on value-adding activities in order to reduce waste.

Womack and Jones differentiate three types of activities in the value streams [104]:

- Value-added – activities which unambiguously create value
- Type one muda (jap. wastefulness) – activities which create no value but seem to be unavoidable with current technologies or production assets
- Type two muda – activities which create no value and are immediately avoidable

Activities can be [105]:

- in whole or part unnecessary and wasteful (and therefore, should be eliminated),
- supporting the value-adding activities (which should be reduced as far as possible),
- customer value-adding (which should be continuously improved).

When the value stream with the corresponding value-adding and non-value adding activities is identified, the resources will be used effectively and optimized production processes will be achieved.

3. Lean flow of the stream

The principle of the lean flow of the stream can significantly help in the elimination of the waste. The lean flow of the stream is defined as a "*progressive achievement of tasks along the value stream so that a product proceeds from design to launch, order to delivery and raw materials into the hands of the customer with no stoppages, scrap or backflows*" [104].

This lean principle states that the work should flow steadily without any major interruptions from one value adding activity to the next one. If the lean flow of the stream is achieved, then all the obstacles and bottlenecks are prevented.

4. Client-pulled flow

The production system should react to customer demand; there should be a client-pulled flow of products. A client-pulled flow is defined as "*a system of cascading production and delivery instructions from downstream to upstream in which nothing is produced by the upstream supplier until the downstream customer signals a need*" [104].

The company should identify who the internal and the external clients of the processes or products are. Then, the processes have to be designed in such way that they are triggered by the downstream client without producing anything which is not triggered and without pushing products to the customers.

5. Perfection

When the first four lean principles are achieved, the system has already improved. The fifth lean principle is to strive for perfection. It is defined as "*the complete elimination of muda so that all activities along the value stream create value*" [104].

Since the production system became leaner and faster through the first four principles it is easier than ever to identify and eliminate waste and create a never-ending process of striving for perfection, or in other words a process in which every activity is a value-adding activity, the process is capable (produces a good result every time), available (produces the desired output, not just the desired quality, every time), adequate (does not cause delay), flexible, and linked by continuous flow. If one of these factors fails some waste is produced (see below) [105].

The fifth principle should be ensured through a continuous improvement process by continuously questioning the status quo by every employee.

5.3.5. Process approach

The manufacturing system is an input-output model. The inputs and outputs can by tangible (e.g. materials, components or equipment) or intangible (e.g. data, information or knowledge). A process which is a set of interrelated or interacting activities uses those inputs in order to deliver an intended result [106].

A different definition sees the process as a "*sequence of goal-oriented activities which generate measurable added value for the customer, support the company´s goal achievement and are carried out according to certain rules* [107]".

Figure 33 Process

The organization can only function properly and effectively if all the linked activities and processes are identified. The purpose of the process approach is to enhance an organization´s effectiveness and efficiency in achieving its defined objectives. The efficiency of a process is defined as the ratio of achieved resources and used resources; and the effectiveness of the process is defined as the ability to achieve the desired results.

All companies use processes in order to operate as an integrated and complete system and to achieve their objectives. The ISO 9001 promotes the adoption of a process approach when developing, implementing and improving the effectiveness of a quality management system, to enhance customer satisfaction by meeting customer requirements [108].

Lean´s ultimate goal is to create processes which are waste-free in order to achieve customer satisfaction. The process chains always have to be understood as a customer-supplier relationship [109].

The process approach is the foundation for lean manufacturing as well as the foundation for any other continuous improvement program. In a process oriented organization, the focus is on the optimization of the entire value chain. Problems such as customer dissatisfaction, employee frustration, duplicated work, high costs, and bottlenecks arise when processes are not well-designed. In order to prevent that, lean identifies 7 (8) types of waste which need to be eliminated.

5.3.6. Types of waste

In order to specify the value for the customer, lean aims to identify and classify waste which needs to be eliminated in processes in order to deliver more value to the customer. Womack and Jones define waste as any human activity which absorbs resources but creates no value. Ohno has identified seven types of waste which are also known as Ohno´s seven muda. Later, they were expanded by an additional one. Those are [104]:

Figure 34 Eight types of waste identified by lean manufacturing

1. Overproduction

The waste of overproduction states that the products are produced in a too big quantity or produced ahead, before they are needed by the next process customer. This leads to excessive inventory. Overproduction can be caused by large batch sizes, unreliable processes, unstable schedules, unbalanced cells or departments, working to forecast or to inaccurate information and to actual demand [110].

Ohno believed that the waste of overproduction was the worst of all wastes since it is the root of many other wastes or problems and obscures the need for improvement [104].

In order to eliminate or reduce overproduction, overproduction first needs to be understood. Companies should perform value stream mapping or process mapping and identify where overproduction happens. Then, lean manufacturing principles have to be implemented in order to plan production better in the future. Just-in-Time principle can ensure the pull of production through the processes which will eliminate the overproduction [110].

2. Inventory excess

There are three types of inventory excess. Those are as an excess of raw material, work in progress and finished goods stock that is held. Inventory excess is simply defined as having more than just the minimum necessary stock. Every piece of inventory that is held has a cost associated with it. Unnecessary inventory which accumulates before or after a process is an indication that continuous flow is not being achieved. It can be caused by the lack of work flow which forces inventory build-up between processes as well as by large batch sizes, failure to observe stagnant materials, incapable processes, long changeover time, not adhering to procedures [110].

Excess inventory increases lead time, prevents rapid identification of problems and increases space that would affect communication [104].

In order to eliminate inventory excess, manufacturers should work according to main principles of lean manufacturing and make value flow at the pull of the customer with the Just-in-Time production [104].

3. Defects

Defects are the products or services which deviate from what the customer requires or specifies. Defects cause the waste of correction which includes additional work performed on a product or service. Defects are responsible for immediate and long term costs. The costs associated with defects are the costs of problem solving, materials, rework, rescheduling materials, setup, transport, paperwork, increased lead times, delivery failures and potentially lost customers who take their custom elsewhere [110].

Defects can be caused by unclear operating procedures or specifications, inadequate training, skills shortage, incapable processes, incapable suppliers, operator error, excessive stock, transportation [110].

Some of the techniques for eliminating defects are implementing standard operations procedures and ensuring training [110].

4. Excess transportation

This type of waste includes all activities associated with the transportation or movement of materials or products from one place to another which does not add value for the customer. Excess transportation may be caused by poor layouts, lengthy or complex material handling, and large batch sizes, working with faster rate than customer demand or multiple storage locations [110].

Excessive transportation often leads to operations having to wait for products to be delivered due to delays which creates costs and extends lead times, affects productivity and creates delivery problems [110].

In order to avoid excess transport, layouts should be changed in order to make the processes as close together as possible and to achieve material flow directly from process to process without any significant delays [110].

5. Excess movements

Unnecessary movements refer to moving products and layouts which are classified as waste. Excess movements can be caused by poor workstation layout, excessive walking, bending, reaching, poor method design, poor workplace organization, large batch sizes or reorientation of materials [110].

Excess movements create a decrease in work efficiency. Another potential symptom of excess movements could be health problems of workers, or wear or premature breakdowns in equipment. When excess movement is reduced, it brings an increase in efficiency and makes the work easier for employees [110].

6. Waiting time

The waste of waiting occurs when work is done slowly or not done at all because of the waiting for the previous step in the process, waiting for parts, machines or colleagues [110]. Waste of waiting is directly connected to flow and directly relevant to lead time.

It occurs when 2 interdependent processes are not completely synchronized. Some examples for the cause of waste made by waiting are the lack of material, failures in machinery for processing, poor man / machine coordination, long changeovers, unreliable processes or quality, batch completion, and the time that is required to perform rework [110].

Waiting can be reduced by balancing production processes, improving machine reliability and quality, reducing overproduction and inventory. Furthermore, ensuring that standards and methods are clear and using visual methods of planning can ensure that every worker clearly knows what is required from him [110].

7. Overprocessing

Overprocessing adds more value to the product than the customer is willing to pay for. Overprocessing costs money regarding the time of the staff, used materials and the wear on the equipment. Some examples of overprocessing include painting unseen areas, unnecessary tight tolerances, cleaning and polishing beyond the required level [110].

The goal of lean is to spend more time and money on creating the value for the customer. By understanding exactly what the customer wants to pay for in a product, the waste of overprocessing can be avoided and it can be used for other activities which actually add value to the product.

8. Not utilizing talent

Not utilizing talent is not one of the 7 wastes which are a part of the original Toyota Production System. However, organizations today increasingly recognize the waste of not utilizing the talent, skills and knowledge of their employees which can have detrimental effect on an organization. There can be big benefits if the companies recognize the value of skills and improvement ideas.

The waste of not utilizing talent includes assigning staff to wrong tasks, wasteful administration tasks, poor communication, lack of teamwork, poor management, insufficient training [111].

Key solutions for eliminating this kind of waste are empowering the employees to discover and develop their skills, stopping micromanaging and increasing training [111].

There are many techniques to identify and reduce waste, but lean manufacturing wishes to completely prevent waste from occurring.

5.4. Volkswagen Production System

The Volkswagen Group introduced a holistic production system which became the standardized production system for the whole Group in 2008 [112]. Volkswagen Production system is defined as a value-added, synchronous production system with a goal to establish a value chain-oriented and a synchronous Company [113].

The objective of the Volkswagen Production System is to orient all practiced activities to value chain and to abolish non-value chained processes whereas the success is not measured by cost and price but the particular significance is attached to the aspect of quality [113].

The Volkswagen Production System encompasses all the principles, standards, methods and framework elements the Group needs for everyday implementing of stable, waste-free processes [114].

The Volkswagen Group has developed the principles of its production system, as many other automobile manufacturers, following the example of Toyota; based on the lean principles. The Volkswagen Production System is supported by four principles: takt, flow, pull and perfection, whereas the principle of perfection includes the zero-defect principle. There is an 80 percent overlap with TPS principles. However, this does not mean that Volkswagen has not pursued its own path [112].

The work organization at VW remains influenced by its own traditions, for example by an understanding of teamwork, self-organization and an approach which includes continuous improvement activities based on cross-functional cooperation of shop floor actors and the specialists of the supporting areas [112].

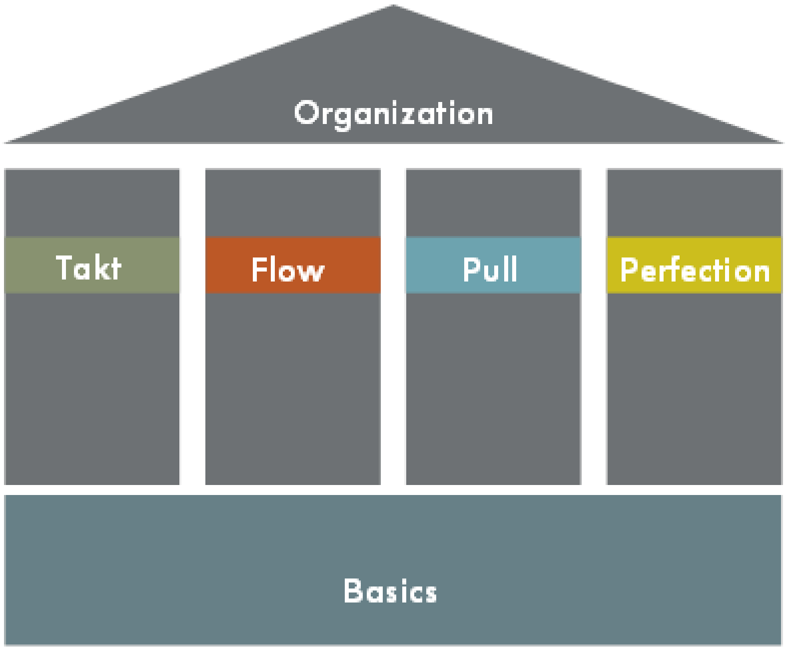

Figure 35 The Volkswagen Production System [114]

The Volkswagen Production System has a structure of a house with “Basics” which represent the foundation and the four principles which are the pillars of the house and ensure its stability. The “Basics” include methods and principles which enable the achievement of the four principles.

Takt

The leitmotiv of this production system is “to produce only what the customer needs” and it applies to all customer-supplier relationships. According to this principle, overproduction is avoided.

The vision of the “takt” principle is that the customer defines the rhythm of production. Therefore, the customer defines the rhythm of all the supporting process and creates a constant takt level. In such a way it is possible to achieve stabile, robust and cyclic production processes and waste elimination [114].

Flow

In the ideal production, the material is constantly flowing, stocks are reduced, losses are avoided and short cycle time is ensured. The "flow" principle means that material and information flow according to the customer takt which means that processes and activities are organized according to the production process and are distributed to the individual workstations [114].

The processing in a single-piece flow which is supported by the visual management and direct forwarding to the subsequent process makes it possible for quality problems to be eliminated. The flow principle achieves a safe, continuous supply of the production and reduces the cycle time because all the necessary standardized buffer times are eliminated [114].

Pull

If it is not possible to accomplish a steady flow, the pull principle allows to deliver according to clear rules – what has been consumed will be produced. It prevents overproduction [114].

The pull principle says that the upcoming process retrieves only the parts and information which are needed from the previous process. At the same time, the previous process, produces only what the following process consumes. The supply security is important to achieve high process stability and fast responsiveness. The pull system makes it possible to achieve a reduction in inventories, investments and a control of expenses. Due to this process improvement, it is possible to minimize the cycle times and costs [114].

Perfection

The Volkswagen Production System strives for perfection according to its goal – "zero-defect quality". However, in this production system, every mistake is considered to be an opportunity for improvement by making sure that every mistake is made only once. This production system strives to prevent errors, and identifies and rectifies all the problems on the spot [114].

5.5. Closure

Operational excellence has now been defined, along with the methods used in order to achieve it. The main focus was on lean manufacturing since lean principles are the principles the Volkswagen Production System is based on. The thesis will now focus on finding the correlation between digitalization and lean manufacturing.

6. The correlation between lean manufacturing and digitalization

When the Toyota Production System was first developed, the information and communication technologies that are available today and enable digitalization did not exist. Digitalization of the industrial processes as well as the supporting processes causes classic approaches used in companies to be questioned.

Lean manufacturing is now faced with new chances and risks. One of the dominating questions is whether lean methodology can still survive in digitalized manufacturing companies as the foundation of production system principles in Industry 4.0 environment where everything is becoming intelligent and connected.

6.1. Lean and digitalization

Implementing digital technologies in businesses can have many benefits for businesses as it enables re-inventing products, services, processes and relationships with customers and suppliers.

To get the answer to the question, how lean and digitalization come together, the objectives of lean manufacturing and the objectives of digitalization shall be discussed.

Lean objectives

Lean principles show that the primary focus of lean is customer orientation. Lean processes create products exactly according to customer demand. Lean also aims to achieve waste-free processes by eliminating non-value adding activities by following the 5 lean principles. Lean promotes continuous improvement which results in achieving efficient processes. Another important factor of lean is that it avoids overloading of employees and aims to enhance their engagement.

Digitalization objectives

As already mentioned, the most important reason why companies implement digital technologies in their businesses is to improve customer experience. When a company implements digital technologies, it can also expect many other benefits as described in the following.

The figure from "The Future of Work" research shows that the biggest benefit after implementing digital technologies within companies is that the companies will be able to respond faster to the changing needs. They will also be able to significantly optimize their business processes and in such way increase revenue and profit.

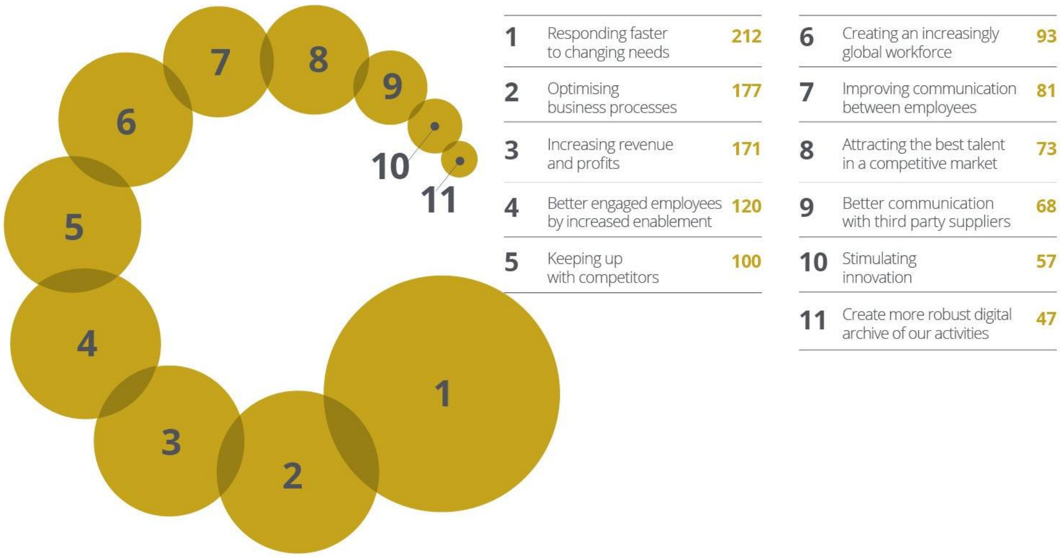

Figure 36 Benefits experienced after adopting digital technologies within organizations [63]

The customers and the market expect more and more from the manufacturers as already discussed. Companies need to understand the changes in customer requirements and respond to them accordingly. Responding fast to the changing needs can only be possible with the use of digital technologies nowadays. There are multiple ways of how the company can leverage digital technologies in order to respond faster to the changes on the market or to optimize their business.

It became apparent that the implementations of digital technologies in companies as well as the implementation of lean bring similar benefits. Digital technologies support companies to achieve customer satisfaction by being able to respond faster to the changing customer needs. Lean responds to customer needs by identifying exactly what the customer wants and by delivering that value in the right amount, quality in the right time, at the right place.

They both also result in optimized processes which in the end bring economic success. Apparently, lean and digitalization have similar objectives, but the question if they can co-exist in manufacturing processes still remains. The answer to this question will be given by comparing the two approaches in manufacturing companies.

6.2. Lean manufacturing in Industry 4.0

In order to get the answer to the question whether lean approach should be used in the digitalized manufacturing companies; it will first be discussed how Industry 4.0 concepts and technologies can enable the optimization of processes in those companies which will be supported with examples. Since this thesis will aim to answer if lean manufacturing will still be valid in Industry 4.0, the examples will be compared to the 5 lean principles.

Lean and Industry 4.0 are much more similar than they seem. Both lean and Industry 4.0 have a common goal and it is to seek ways and solutions to deal with the ever-increasing complexity which is enormously resource-intensive. The efficient complexity handling is the prerequisite for the future competitiveness of a large number of manufacturing companies [115].

Lean aims to continuously improve the processes by waste avoidance in processes which results in an increase in productivity and flexibility. On the other hand, digitalization in production, Industry 4.0 significantly influences the production environment with radical changes in the execution of operations. Manufacturing set up is becoming more complex than people could have imagined.

Industry 4.0 promises to optimize the processes by making the factories smart, by connecting all the products, machines and the whole environment. In other words, it connects every entity in the value stream, which enables them to share information among each other. It enables real-time planning of production plans, along with dynamic self-optimization [116].

In addition to increasing efficiency, Industry 4.0 also offers a wide range of other potentials such as: individualization of customer requirements, flexibility, added value through new services, optimized decision-making and demographic-friendly work organization [29].

The goal of Cyber-Physical Systems as the core element of Industry 4.0 is also to increase productivity and flexibility through real-time planning and dynamic self-optimization. The core ideas of lean and Industry 4.0 are very similar, but the approaches are different. Lean reduces the complexity by decomposing units into smaller, more manageable units and the use of self-regulating control circuits. Industry 4.0 attempts to master the complexity through cyber-physical systems and to reduce the complexity by means of assistance systems from the point of view of the user [117].

Lean´s guideline "first *process then technology*" ensures that the technology supports the value adding processes rather than waste [118].

Both lean and Industry 4.0 have a common goal but having a common goal does not immediately mean that lean and Industry 4.0 can co-exist. The question that is still unanswered, when more and more companies are implementing the concepts of Industry 4.0 is if Industry 4.0 can even work in a manufacturing environment which is "controlled" by the lean principles and if lean manufacturing is even needed in Industry 4.0 environment.

6.2.1. Lean Automation

Lean approach has already been questioned when Computer Integrated Manufacturing (CIM) was first introduced. Many experts thought that lean conflicted with automation. However, the contrary was shown. Lean took the idea of combining automation technology and lean manufacturing which was shown to be very beneficial after the peak of CIM. Ohno has already stated in the 1960s that lean manufacturing does not exclude automation, when he introduced the principle of "autonomation" which describes that the processes should be automated and only supervised by employee [119].

Autonomation is a feature of machine design which enables the lean principle of jidoka. It stands for the automation of manual processes which include inspection; for example, when a problem occurs the equipment should stop automatically and not allow defects to further proceed through the line. Only when a defect is detected would a human intervention be required. Hence automation in production has played an important role right from the inception of lean manufacturing [116].

The principle of autonomation corresponds to Industry 4.0, since Industry 4.0 can be considered as an advancement in this field. Introducing information and communication systems into industrial networks leads to a steep rise in the degree of automation [116].

With an increasing degree of implementation of Industry 4.0 many companies face the challenge of combining Industry 4.0 with their existing production system.

6.2.2. Industry 4.0 requirements

Industry 4.0 pursues a customer-orientation business and a customer-oriented process design. The processes in Industry 4.0 have to be automated. They can only be automated only if they are clearly defined, including measurable process results, customers and suppliers, resources, etc. This means that in order to implement Industry 4.0, processes must first be designed efficiently and the customer-supplier relationship must be clearly defined [120].

Process approach

It is obvious that the process approach is the prerequisite for Industry 4.0. Only the production system which pursues the goal of an efficient and customer-oriented process design can be qualified for the successful implementation of Industry 4.0.

Organizations which operate in a process-oriented manner are oriented towards the market and operate according to the requirements and wishes of the end customer. The focus of process orientation is the optimization of the entire value-added process. If companies are based on a process-oriented organizational form, they can react to customer requirements and market changes more flexible [120].

One example of the Industry 4.0 requirement for the process approach is the following. Manufacturing processes will be monitored with sensors and actuators in the Industry 4.0 concept and the recorded data will be processed into Smart Data. In order to generate Big Data into Smart Data, the information recipient must be known, the process must be fully described and the rules or algorithms for data processing must be defined. If the underlying processes and interfaces are not defined sufficiently, the implementation of Industry 4.0 will not provide the hoped-for target contribution. Only when the processes and control circuits are developed, the predecessor and successor processes are defined, the interfaces described, can the targeted digitalization and automation take place [120].

6.2.3. Lean as the enabler of Industry 4.0

The importance of customer orientation and the design of processes will increase with Industry 4.0. Lean promotes process understanding and creates a process orientation within the organization. It designs efficient, customer oriented processes which fulfill the prerequisite of Industry 4.0 and enable its implementation. Industry 4.0 can only be implemented in efficient processes since it alone cannot optimize inefficient processes. The automation and digitalization of wasteful processes would not improve those processes. An inefficient process which is automated or digitally supported would still remain an inefficient process.

Lean processes, or processes without waste, make a solid foundation for implementing Industry 4.0 and making it possible to use its advantages. In other words, lean is the prerequisite of Industry 4.0 since it achieves efficient and effective processes before the implementation of the concept.

Companies will need to have a certain level of maturity of the production system which is based on lean principles before they implement the technical solutions of Industry 4.0 on it [120]. Then, Industry 4.0 technologies can be used to further improve the processes.

Since lean can be seen as an excellent enabler of Industry 4.0, the question that remains is what happens to the lean principles when Industry 4.0 concepts are already implemented. The thesis will now aim to answer this question with examples.

6.2.4. Lean principles in Industry 4.0

Lean principles have been considered to be best-practice when responding to the challenges of the dynamic market, especially in a variant-rich serial production, because of its ability of achieving above-average business success with efficient solutions and simple means, mostly without IT support. The question is, if is it possible to achieve the 5 lean principles easier with IT support using Industry 4.0 concepts.

6.2.4.1. Definition of value

As already defined, this lean principle shows the importance of identifying the value of a product or a service as perceived by the customer. Today, it is easier than ever to identify customer´s needs with the use of new technologies.

1. **Co-creation with customers**

It has already been discussed that the customers have evolved from just passive receivers of products or services. They need to be integrated in business processes. Developments in information and communication technologies such as video conferencing, teleconferencing or instant messaging allowing interpersonal communication and resource exchange enable customer integration in business processes. The concepts which include open innovation, such as co-creation, which is popular in cyber-physical product-service systems and Industry 4.0, offer new ways of innovation which are enabled by the networked eco-system Industry 4.0 creates.

The term “co-creation”, also named “open source” defines innovation as an open process which is not supported by a single company, but customers work together with companies in order to develop a product or a service. Co-creation can be implemented in any phase of the product design (from customer requirements identification to prototype testing). It is very beneficial to companies since they get an early response to product ideas and in case the ideas fail, they will at least fail early [122].

In the end, co-creation results in benefits for the company since the company know what the exact customer requirements are; and in benefits for the customers because they get the exact product they need. When customers are integrated in the product or service design, the relationship between the customer and the company becomes stronger and trust is enhanced which means that the customers will stay loyal.

In co-creation the product is constantly being improved by the community and does not depend on the development cycles of the company which adds value to the product. Also, it has been proven that open source products and solutions are often cheaper than conventional products which appeals to additional customers [69].

Even if the customers are not involved in the process of designing the products, companies can still make use of digital technologies to create a better product for their customers. Companies can use data to discover and evaluate what products are needed on the market.

2. Big Data analytics

Industry 4.0 employs techniques for customer and market research. Big Data tools enable the gathering of data generated from customers on social media, mobile devices or other channels in order to analyze unexpected patterns in business activities and to predict and make better decisions when it comes to identifying constantly changing demand patterns, or in other words, identifying value as perceived by the customer.

Industry 4.0 technologies and tools make it easier than ever to understand the customer demand and make it possible to immediately transfer the demand data in the supply chain. Big data analytics can be used to predict the customers' need for new products, but also for spare parts. Companies will meet customers´ ever-changing preferences by using Big Data analytics. Customers will get the exact product they wanted which will improve their satisfaction.

72% of manufacturing enterprises predict their use of data analytics will substantially improve customer relationships and customer intelligence along the product life cycle [123]. The use of Big Data analytics can help create new growth opportunities and is the basis for customized products.

3. Data from smart products

Nowadays, customers do not only want personalized products, but also products which are smart. Digital technologies make it possible for companies to offer their customers smart products which are an upgrade of technical products.

Smart products are enabled by sensors and connectivity in products which improve their performance and safety; enables connections to mobile applications which improves user experience. Such products can for example be controlled via apps or machines whose maintenance status can be analyzed remotely. Also products can be made smart by using advanced materials in order to improve performance [124].

Even after smart products are sold to the customer, they can still bring value for the company. Smart products can capture and track usage data from customers. The company can then collect the corresponding data produced on such products, and the data can then be sent to smart factories in order to utilize it and make advantage of it. The manufacturer can identify customers´ needs and behaviors from the data generated on smart products in order to provide improvements, more sustainable products and solutions [125]. The insight in customer data can enable future company´s success.

The identification of the value as perceived by the customer can be made much easier by the use of digital technologies which will make it possible for the company to organize itself in a customer-centric way. Big Data analytics in customer and market research which make it possible for the company to get customers´ insights and integrating the customers in the product creation process will make it possible for the company to only produce according to the customers´ needs. It is obvious that digital tools enable the first lean principle.

After the company has identified what value the customer places upon their products and services, digital technologies help companies further by enabling them to offer new kinds of products, services or relationships to their customers. Some of the possibilities enabled by digital technologies are the following:

- **Individualization of products**

Customers today have highly individualized requirements on their products. Nowadays, products and services can be further customized using the possibilities of highly automated factories and the use of Internet. Companies will need to take the advantages of the concept of Industry 4.0 in order to make the products and services more and more individual. The goal of Industry 4.0 is to produce personalized products individually in serial production.

The basis for combining serial production and individualized manufacturing are the concepts of horizontal integration and decentralization which enable the availability of all relevant information in real time, the networking if all factors involved in the creation of value and the ability to be able to derive the optimum value flow from the data at any time [126].
When the production is flexible and automated, individual configuration of products can be automatically passed through the machine control in through the production planning process. The machine will configure itself at runtime so that the individual order can be handled [36].

If the products are individualized, they meet individual customer requirements. In such way, companies will be able to attract new and increase the loyalty of existing customers. On the other hand, due to the high individuality of the products/services which meet high customer requirements, products or services can be sold for higher prices. In this way it is possible to offer more value for the customers through individualized production which is enabled by Industry 4.0 concepts [127].

- **Smart services**

Already mentioned smart products are oftentimes offered together with the corresponding services. Nowadays, purchasing decisions are increasingly being made on the basis of the services that come with the product. In many cases, services have become a more important market differentiator than the product itself [56].Offering products along with smart services can be very beneficial for the company.

- **Availability on demand**

Since there is a trend among customers that the possession of objects becoming less important to them than their availability, companies can use the possibilities of digital technologies to provide new ways of doing business by offering products or services on demand. Products or services on demand are shared among people and paid per use. Since more people use them, the variants of those products or services are becoming less important. Companies will be able to sell availability of products and not products itself which will also attract risk-averse customers who do not want to make bigger investments.

These were just 3 examples of how digital technologies can help companies react to the requirements of the customer, after the company had identified those requirements using the first principle of lean manufacturing.

6.2.4.2. Identification of the value stream

The identification of the value stream means that the processes and activities the product has to go through have to be identified in order to differentiate which activities add and which activities do not add value and in the end to be able use all the resources in an effective way by eliminating or reducing the non-value adding activities.

1. **Smart factory**

The concept of Industry 4.0 enables smart factories which have the ability to connect all the products, machines and the whole environment in the factory. The connected factory enabled by the Internet of Things makes it possible to link the “unlinked” automated cells so that the overall production system can be connected to for e.g. diagnostics and other monitoring applications. The Internet of Things achieves monitoring and tracking of all the processes and entities in a smart factory in real-time. Since all processes and entities in smart factories are connected, transparency is achieved across the whole value chain and it is easy to identify the value stream. When the value stream is identified, it is possible to differentiate the activities which add value and the ones that do not. The Internet of Things makes it possible to identify inefficiencies and the potential for improvement in real-time. Such potential can still be large, even though the whole value chain is connected.

It is obvious that the second principle of lean is enabled to the fullest in the smart factories identifying the value stream becomes automatic and updated in real-time with the Internet of Things which makes it easier to identify the non-value adding activities which can then be reduced or eliminated.

Even without first recognizing and eliminating waste, smart factories enable production with much less waste than traditional factories.

2. Horizontal integration through value networks

Horizontal integration through value networks involves connecting every entity in the value stream which consists of suppliers, manufacturers, traders and customers and enables the transfer of data among them. Each of them transparently receives data about the others´ supply levels, places and fulfills orders automatically or triggers maintenance and upgrades. Such integration and transparency enables the chain to compensate for sudden interruptions [128].

The concept of horizontal integration, just like the concept of smart factories, makes it possible to achieve transparency and identify the entire value stream, but this time even outside of the own company. When a fully automated communication is achieved across the whole value chain it is possible to identify where possible improvements could be implemented and to react to changes faster and carry out production processes more efficiently [45].

Collaborative manufacturing

The term “collaborative manufacturing” stands for the integration of companies into networks which enables them to unite their competences through the entire value chain. This networking is enabled by the horizontal integration in Industry 4.0 via embedded systems which make it possible to virtualize processes and supply chains to achieve an immediate, automatic information trade between the companies [127].

Inappropriate transfer of information between manufacturers and suppliers in the value stream can create significant waste. Every participant in the value stream has to be informed with the right information regularly. The virtualization of processes or the virtualization of the supply-chain which is enabled by Industry 4.0 concept of collaborative manufacturing makes it possible to achieve immediate and automatic feedback to other participants in the value chain [116].

Collaborative manufacturing can result in an increase in flexibility and transparency which will be achieved along the supply chain. Networking departments, partners, suppliers will enable smooth production processes, according to lean principles.

Smart factories and horizontal integration which also enables collaborative manufacturing make it possible for all the participants in the value chain to be synchronized since all the processes are transparent. Therefore, the supply chain as a whole can be identified and optimized. The main advantage Industry 4.0 brings for the identification of the value stream is the real-time availability of data and services. The value stream in the Industry 4.0 concept will not be a value stream based on time-delayed data image of reality but will be identified in real-time, all the time.

6.2.4.3. Lean flow of the stream

The lean flow of the stream is achieved when the work is flowing steadily without any interruption between value adding activities, which means that all the obstacles and bottlenecks are prevented. Stabile production processes are the prerequisite for designing just-in-time suitable value streams [129].

1. Assistance systems

Instabilities, for example, in the form of high reject rates, strongly fluctuating cycle times or frequent machine stops, must first be eliminated in order to achieve the lean flow of the stream. Digital tools and systems can be implemented in order to help in case of instabilities [129]. Lean flow of the stream can be threatened by any mistakes employees make or if there is any problem that cannot be solved directly.

One possibility is to stabilize cycle times in employee-intensive areas at a uniform level and to avoid mistakes by the means of digital or video based worker assistance systems [129]. Assistance systems can help employees carry out their tasks by providing them with information, instructions, or even video tutorials which will make the processes easier which will enable the lean flow of the stream.

Assistance systems also show that the concept of Industry 4.0 corresponds to the concept of lean manufacturing since lean supports technology implementing only if it helps reduce waste, which is the case with the assistance systems.

2. Predictive maintenance

Industry 4.0 enables the networking of machines, products and components which allows the continuous monitoring of the condition of in-service machine components. Data on machines status and production is being continuously acquired by sensors and shared online which makes it possible to check the status of equipment and anticipate corrective maintenance more precisely. With the use of stochastic algorithms it is possible to calculate the probability of future production events weeks, months or sometimes years ahead [130].

If the maintenance is anticipated, the downtimes of the machines can be reduced and alternative machines for the production can be found in those periods so the bottlenecks can be prevented [130].

Condition monitoring

Condition monitoring is a subset of predictive maintenance which is a combination of suitable data processing routines and user-friendly visualization which helps systematic problem solving and enables faster identification of problem causes which is supported by the vertical integration of the IT systems at individual workstations in Industry 4.0.

3. Cyber-Physical Systems

Cyber-Physical Systems enable the communication of machines and integrated systems among each other, but also with people. Objects in smart factories are equipped with knowledge which enables decentralized and fluid production concepts. Immediate communication is possible with the networked objects if there are enough available resources in real-time.

Real-time inventory tracking is enabled. If there are not enough resources, the smart factory has the ability to make decentralized decisions and to re-route work which will enable continuous flow and prevent the happening of bottlenecks if the resources have to be waited upon [116].

If there are enough resources, the product will be manufactured and find its own path through to factory to the distribution point.
CPS enables processes to be analyzed; corresponding improvement potentials to be derived and suggested to the employee, whereby the production processes are designed in such way to generate the overall optimum for the company. CPS will enable decentralized and lean flow of the production processes.

4. Internet of Things and item tagging

The Internet of Things is equipped with different integrated devices for communication which manage the information about transported goods [116]. In order to track if the lean flow of the stream is established, with Industry 4.0 concepts it is possible to know any products location, condition and history by tagging the product with an RFID tag for example and having it connected to the Internet of Things. RFID makes it possible to wirelessly track individual items throughout the process chain in real time. With RFIDs connected to the Internet of Things it will be possible to track item´s origin, status, and destination. It will make it possible to discover if an item is not where it should be immediately which will ensure that the waiting times on items get reduced and ensure that the products reach the correct destination and reduce the lead times of distribution [116].

The connectivity enabled by the Internet of Things will also enable the relocation of orders and optimization of travel roots which promotes lean flow of the stream with Just-in-Time delivery and allows customers to track the status of their deliveries. The Internet of Things will also make it possible to optimize travel routes [116].

Also, if the smart factory discovers that an item is not where it is supposed to be, it has the capability to optimize itself autonomously and to reduce the waiting time on that item enabled by the concepts of item tagging and the Internet of Things which will make it possible to reduce the flow time by optimizing the material flow.

The four examples above show that it is possible to achieve the lean flow of the stream by implementing digitalization in production system.

6.2.4.4. Client-pulled flow

The production system should act according to the pull principle which means that any operation should be only performed when it is required from the following operation. There should be no push production.

1. **E-Kanban**

If there is an improper track of material quantity supplied to the production line and alterations in schedule after material supply it can severely affect the pull production system.

The use of e-Kanban system can enable an automatic pull system through automatic material replenishment monitoring schedule tracking and Kanban updating facilities of Industry 4.0. E-

Kanban systems can recognize missing and empty bins automatically via sensors and trigger replenishment. The data about the charging level of the bins can be transmitted wirelessly in real-time [116].

2. Horizontal integration of the IT system

The implementation of horizontal integration enables better integration of customers into the value-added process. It will increase flexibility and transparency along the value stream. The horizontal integration is the prerequisite for achieving a product-driven process. It will enable a real-time feedback in order to be able to respond to disturbances in real-time.

Suppliers can gain insight of warehouses and entire supply chains with the possibilities enabled by Industry 4.0 concepts. It will be possible to automate the ordering process, or in other words, for a customer to individually trigger a production order which is then independently controlled by the production process [116].

When an order is received in the Smart Factory, it is immediately forwarded directly to the production cells. It is possible that the customer specifies the features he wants on a smart phone or computer, online, and that the order is directly transmitted to the production system. Since there are no formalities between the customers´ order and the start of the production, the perfect pull system is achieved.

Real-time information makes it possible to share information in the end-to-end value chain. It enables the just-in-time production.

With the new concepts and technologies, the pull principle can be achieved automatically.

6.2.4.5. Perfection

The last lean principle means that the organization should strive for perfection by elimination of all types of waste and by creating a continuous, never-ending improvement process. The goal of the continuous improvement is to strive for processes in which every activity brings value to the products, or in other words such improvement achieves waste-free processes. Continuous improvement heavily relies on employee participation.

1. Big Data

In order to continually improve, companies need to extract and collect data from all parts of their processes. Continuous improvement is only possible with goals. In traditional continuous improvement methods, such goals are usually based on historical performance.

Industry 4.0 enables horizontal, vertical and end-to-end connectivity and networking. All those concepts enable transparency of processes since the production equipment gathers data from sensors and computers. The data is transparent to everyone on the vertical line of the value stream as well as on the horizontal line of the value stream.

The gathered data can be transformed to information which can be used for continuous improvement since the goals for continuous improvement processes can be set based on real-time data.

2. Machine learning

There will be an increase of non-human actors in the production which will have the abilities of self-control and self-optimization and with such way achieve self-learning.

One example of self-learning is the already mentioned machine learning. With machine learning it is possible to improve computer systems performance by exposure to data. Machine learning systems have to ability to learn without being explicitly programmed. Machine learning automatically discovers patterns in data and uses those patterns to make predictions.

Employee engagement

The perfection principle should be achieved through continues improvement by continuously questioning the status quo by every employee. Lean is a philosophy that strongly focuses on employee engagement. Organizations cannot change unless their people do and that is why lean recognizes the need to magnify the commitment of all employees from the bottom line to top management to improve constantly. It is one of the lean focuses that the employees have the right skills and the necessary perspective to understand their needs and to be able to work efficiently, making the right decisions and they strive for continuous improvement and perfection [131].

The transitions to new technologies will come with new requirements on employees skills as already described. Lean´s focus of employee engagement is a very important factor because only when the employees have the right set of skills and they continue to develop suggestions for improvement, can a lean organization be completely achieved.

Summary

Lean pursues customer-oriented business and process design. Customer orientation and process design will stay the main principle also in Industry 4.0 and will continue to grow which will be enabled by the applications of new digital technologies.

The production built on lean principles will be enriched by new technologies enabled by the concept of Industry 4.0 which will increase and improve the interactions between people and technology. On the other hand, people will get support in decision making. Some decision made by people in the past will now be made independently by systems which will reduce human mistakes and with it connected waste. When it comes to creative decision making or creative problem solving, people are still needed as the vital part of the factory.

Technology is not the self-purpose of Industry 4.0. It is the basis of Industry 4.0 which enables multiple benefits when implemented. It will make the processes become more efficient. There will be less waste in the processes, the quality of the products will be higher, and the customer will be in the focus of every process more than ever before. Industry 4.0 will enable transparency of every activity which will make continuous process improvements easier.

Taking all of this into consideration, it can be seen that Industry 4.0 will make lean possible in the full sense of the word. With the new possibilities enabled by the concept of Industry 4.0, lean principles will be effectively supported.

It has already been shown that Industry 4.0 requires efficient, stable and standardized processes in order to achieve horizontal, vertical and end-to-end connectivity. Since such processes are achieved by implementing lean, it has been concluded that lean was the enabler of Industry 4.0.

Now, the last section has shown that Industry 4.0 concepts correspond with lean principles. The examples have shown that with the use of the concepts and technologies of Industry 4.0, it will be possible to achieve the 5 lean principles in an easier and a faster way. Thus, Industry 4.0 is the enabler for lean manufacturing and can be used to further improve the processes by drastically increasing the responsiveness towards changes in the value chain which will enable the realization of a true lean enterprise.

It can be concluded that lean processes enable the implementation of Industry 4.0 and that Industry 4.0 enables lean to fulfill its goals to the fullest.

6.2.5. The effects of digitalization on the Volkswagen Production System

As already discussed, the principles of Volkswagen Production System are based on lean principles. In the table below, it is shown which Volkswagen Production System principle corresponds to which lean principle.

VW PS principles	Lean principles
Takt	Definition of value
Flow	Lean flow of the stream
Pull	Client-pulled flow
Perfection	Perfection

Table 1 Comparison of the Volkswagen Production System principles and lean principles

The Volkswagen Production System is based on 4 principles, while as defined by Womack and Jones, the lean approach consists of 5 principles. The second lean principle “Identification of the value stream” corresponds to one of the foundations of the VW PS, the “Consistent elimination of any waste”. Volkswagen recognizes 9 types of waste and defines waste as everything that does not play a part in value adding [114].

The principles of Volkswagen Production System establish a value chain-oriented and a synchronous Company with reliable and efficient processes which are the prerequisite for Industry 4.0. It will be possible to implement Industry 4.0 on the principles of the VW PS.

Since there is a correlation between lean principles and the principles of the VW PS, and it has already been shown that the lean principles are still followed when using the concepts and technologies of Industry 4.0, the same can be said for a production system which is based on lean principles. Therefore, it can be concluded that the principles of Volkswagen Production System will still have an important role in Industry 4.0.

On the other hand, Industry 4.0 will create more efficient and effective processes which will help the Volkswagen Group to realize their 4 principles and Industry 4.0 technologies will be used to increase their responsiveness to changes along the value chain.

6.3. Recommendation for the Volkswagen Group

6.3.1. Changes in process improvement

Lean principles will define the necessary framework for the implementation of new technologies in the future. As shown in this thesis, the way value streams have been optimized in the past according to the lean principles which will still be valid in the future. The lean methodology will provide the required strategies that define framework for any future technology to come.

Lean processes which are continuously being optimized will be made even more efficient by applying new technologies. Along with the efficiency increase, lean also achieves some increase in flexibility. Past technology milestones have been focused on automation which mostly allowed minimizing failure and reducing production costs. What is significant about the fourth industrial revolution is the drastic improvement not only in efficiency and effectiveness but mostly in flexibility enabled by the responsiveness of the Industry 4.0 concepts.

The concept of connected and communicating production systems will result in the ability to adapt to changes more flexibly. This will allow manufacturing companies to shift production according to changing demands on the market and will make it possible for the company to respond to customer demand more individually. The greater the flexibility of the value chain, the higher the product or service value provided to the customer and thereby for the company. Therefore, digitalization of value-adding processes will bring opportunities to increase competitiveness.

In the past, machines and robots were able to detect errors, whereas humans still had to correct them. Further, defective products could have only been detected at the end of the line of quality assurance. Digitalization on the other hand, brings in smart robots that not only manage to detect failure but also to correct it. So ultimately, next to responsiveness to market changes, digitalization also significantly reduces the quantity of failure and thereby increases the profit.

In order to achieve optimization of the value chain, lean methodology offers lean tools which can be applied manually to the value chain or the process which shall be improved. Digitalization does not only enhance the process optimization, but also finds new ways of performing processes by implementing digital technologies.

The implementation of digital technologies can be very cost-intensive and that is why the right decision needs to be made when it comes to deciding which parts of the processes have to become digitally supported in order to result with products or services which bring profit for the company.

Implementation of digital technologies in processes is not always financially beneficial. Sometimes the cost of technology implementation exceeds the benefits it brings. Ultimately, lean is a superior approach of process improvement, which shall therefore be implemented in every process with improvement potential. Digitalization, on the other hand, shall only be implemented when flexibility needs to be increased by making the value chain connected and smart which then results with an increase in profitability.

6.3.2. Changes in employee skills

New technologies have always brought new ways of doing work, especially in production. This is why digitalization also brings a set of challenges for the companies, such as organizational changes, changes in work tasks and changes in required skills. There will be an increase in automation due to the fact that robots outperform humans in many ways like e.g. performance, precision or error susceptibility. Increasing automation will bring great changes in the daily work flow for many employees, i.e. following the increasing trend of humans working alongside with smart machines and robots. In other words, software and automated processes machines will replace labor in many parts of the business.

As already discussed, the demand of employee skills will change drastically in the new automation age. Therefore, training on the job has to be something worth rethinking to support the transition into the digitalized business.

The Volkswagen Group will need to invest in the so called “digital skills and capabilities” of their employees. Trainings for the employees need to be ensured so they learn new skills, which will help them adjust to the new working conditions.

The demand for new skills and capabilities will also result in a so called “global war for talent”. The Group will have to find ways of attracting talent which has the ability to work with the new tools and technologies.

Ultimately, new jobs have to be created ranging from maintaining and improving the new complexity of the value chain, to using the newly obtained “free time”, enabled by automation, for more creative work. In either way, it will be very important that humans still get to interact with each other to keep up their social skills and mental sanity.

6.3.3. Cultural changes

Digitalization will bring changes throughout all areas of a manufacturing company like Volkswagen. The digitalization of the Volkswagen Group comes with the need for a transformation of all the members of the Group.

Ultimately, there are two major changes digitalization brings. The first one is the change of the product-to-market stream and the second one is the necessary cultural change. The product related changes shall introduce agile development cycles where possible to allow for faster products to market and create a tighter bond with the customer. Further, in order to compete with rest of the digital industry, the required change of culture will require a new generation of leadership.

In order to respond faster to the changes on the market, decisions need to be made faster. Consequently, the decision making process needs to become decentralized in a way that vertical levels need to be reduced.

6.4. Closure

This chapter has shown the correlation between lean manufacturing and digitalization based on examples from manufacturing areas. It has been shown that lean is the prerequisite for Industry 4.0 and that the lean principles will still remain valid in the Industry 4.0 environment. Recommendations for the Volkswagen Group regarding the changes digitalization brings have also been given.

7. Conclusion

Digitalization is rapidly progressing which creates many opportunities for the companies across many industries, but undeniably also risks. Digital transformation does not only stand for the purchasing of digital technologies for the organization. It is about the leveraging of those technologies in order to achieve competiveness on the market and to increase revenue. Digital technologies are just the enablers for the transformation that needs to happen in companies to survive on the ever-changing market with high customer demands.

Companies will face the risk of getting their products or services disrupted if they do not exploit the accessible technological developments and transform their business. Nowadays, there is a risk that even whole industries can get disrupted, not only companies.

Due to the significant changes on the market and the new technologies which are widely accessible today, companies will need to go through digital transformation deploying a new business strategy which will enable them to stay competitive by answering to customer and market needs in a fast and flexible way.

Digitalization in manufacturing companies will be achieved through the implementation of the Industry 4.0 concept. Many manufacturing companies, followed by the success of Toyota and the Toyota Production System based on lean principles have implemented lean manufacturing in their production systems since it is a philosophy with a proven business benefit. Companies which have implemented lean manufacturing in their organization gained a big potential in the field of process improvement. Lean has been a dominant principle when it comes to productivity and efficiency increases in production systems.

Even though there are many who do not believe lean principles will still be needed when all the processes become digitalized, it is to conclude that digital technologies do not improve processes themselves. If there are digital technologies implemented in an inefficient process it only means that the process is still inefficient but uses digital technologies.

This thesis has shown that there are similarities between the drivers behind the lean approach and the drivers behind digitalization since they both share the common trait on meeting the customers' needs and improving their satisfaction while improving business processes. However, lean and digitalization have a difference in their approach.

This thesis has focused on manufacturing companies and has questioned the correlation between lean and the Industry 4.0 concept which increases efficiency, effectiveness and responsiveness to customer demands. It was shown that the main requirement for implementing the concept of Industry 4.0 is having efficient and waste-free processes. The automation and digitalization of wasteful processes would not make those processes any better. The desired savings would not be achieved and the costs of digitalization would be great.

When a company has already implemented the lean approach which promotes process understanding and increases the efficiency of processes, then it is possible to further benefit from digital technologies. Lean processes, or processes without waste make it possible to implement Industry 4.0 and to use its advantages in a way that optimal manufacturing processes can be developed, simulated and validated. Lean and stable processes are the prerequisite for Industry 4.0 and not its consequence. Thus, it was concluded that lean is the perfect solid foundation for Industry 4.0 since digitalization alone cannot help processes improve.

This thesis has also shown that Industry 4.0 concepts and technologies enable the achievement of all five lean principles easier and faster. Industry 4.0 supports the vision of lean and promotes lean manufacturing.

Successful companies should not think they have to change their existing production system build on lean principles. The concepts of Industry 4.0 combined with the established principles of lean will work together perfectly and will enable the collaboration of people, machines and products which will improve the value adding process and enable manufacturing companies to meet the future market requirements.

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