



Volume 8, Issue 1, March 2021

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ATHENS INSTITUTE FOR EDUCATION AND RESEARCH

A World Association of Academics and Researchers

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The current issue is the first of the eighth volume of the *Athens Journal of Technology & Engineering (AJTE)*, published by the [Engineering & Architecture Division](#) of ATINER.

Gregory T. Papanikos, President, ATINER.



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11th Annual International Conference on Civil Engineering **21-24 June 2021, Athens, Greece**

The [Civil Engineering Unit](#) of ATINER is organizing its 11th Annual International Conference on Civil Engineering, 21-24 June 2021, Athens, Greece sponsored by the [Athens Journal of Technology & Engineering](#). The aim of the conference is to bring together academics and researchers of all areas of Civil Engineering other related areas. You may participate as stream leader, presenter of one paper, chair of a session or observer. Please submit a proposal using the form available (<https://www.atiner.gr/2021/FORM-CIV.doc>).

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Conference fees vary from 400€ to 2000€
Details can be found at: <https://www.atiner.gr/2019fees>



Athens Institute for Education and Research

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The [Industrial Engineering Unit](#) of ATINER will hold its 9th Annual International Conference on Industrial, Systems and Design Engineering, 21-24 June 2021, Athens, Greece sponsored by the [Athens Journal of Technology & Engineering](#). The aim of the conference is to bring together academics, researchers and professionals in areas of Industrial, Systems, Design Engineering and related subjects. You may participate as stream leader, presenter of one paper, chair of a session or observer. Please submit a proposal using the form available (<https://www.atiner.gr/2021/FORM-IND.doc>).

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- Abstract Submission: **22 February 2021**
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A Perspective Evolution Methodology of Energy Management in a Subcritical Regenerative Organic Rankine Cycles Operate at Two Temperature Levels

By Ali H. Tarrad*

The waste energy recovery and management philosophy represent a great challenge for scientists. This article outlines a scheme to utilize two different source temperature levels in the range of (160–200) °C. Two regenerative organic Rankine cycles (RORC) were implemented to construct a compound regenerative organic Rankine cycle (CRORC) to improve the energy management of the sources. The method of energy management for these cycles was accomplished by extracting a certain amount of energy from the high-temperature cycle and rejecting it to the working fluid in an economizer at the low-temperature level. R-123 was circulated in the high-temperature cycle due to its high critical temperature at evaporation and condensation temperatures of 150 °C and 50 °C respectively. R-123, R-245fa, R-1233zd-E, and the hydrocarbon R-600a were used as working fluids for the low-temperature cycle at evaporation and condensation temperatures of 130 °C and 35 °C respectively. This technique showed that the first law of thermodynamics efficiency was augmented by (3–5)% for the low-temperature mini-cycle of the (CRORC). The energy consumption at the low-temperature cycle was also reduced by (3–5)%. The latter reduction range accounts for 2% for the total extracted energy for the independent system where both high-temperature and low-temperature cycles were utilized separately. The data showed that increasing the superheat degree from 10 °C to 20°C has enhanced the thermal efficiency of the compound (CRORC) system by (2–4)%. The (CRORC) system of R-123/R600a, R-123/R-123, and R-123/R-245fa fluid pairs exhibited higher thermal efficiency than that of R-123/R-1233zd-E pair by (4.5–6)%, (4–6)% and (3–4)% respectively. The net thermal efficiency of the compound (CRORC) system fell in the range (12–13)% and the low-temperature mini-cycle of the (CRORC) system had a range of (12–14)% for all of the examined operating conditions.

Keywords: *compound cycle, regenerative, energy management, energy recovery*

Introduction

The basic and regenerative, sub-critical, and single pressure (ORC) systems have been adopted in the practical field due to their allowable working operating conditions range and compactness, Le et al. (2014) and Astolfi et al. (2017). Shengjun et al. (2011) investigated the utilization of several working fluids at 80–100 °C in an organic Rankine cycle (ORC). The results proved that isobutene demanded the lowest cost to produce electricity, and the R-152 unit is more compactable. Da Cunha and Souza (2020) simulated a regenerative organic

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Rankine cycle with several extractions at the turbine circulated R-134a as a working fluid. The evaporation temperature was ranged between 60 °C and 100 °C with superheated temperatures of 120 °C, 200 °C, and 300 °C. They concluded that the maximum thermal efficiency and turbine output increase with the evaporation temperature. The turbine output power showed an augmentation with increasing in the superheat temperatures and the thermal efficiency exhibited a declination with superheat temperature increase.

Xi et al. (2013) investigated the performance of three different organic Rankine cycles systems to extract waste heat under the same condition. They found that the double-stage regenerative cycle produced the best thermal efficiency and exergy efficiency under the optimal operating conditions. It was followed by the single-stage regenerative system, and the simple organic Rankine cycle has the worst efficiencies. Javanshir et al. (2017) investigated the optimization of a regenerative Organic Rankine cycle (ORC) using dry working fluids. Butane, iso-Butane, and R113 offer the highest specific net of work output. They concluded that the higher cycle net of work output and thermal efficiency corresponds to the working fluids of higher specific heat and higher critical temperature respectively. Yuan and Zhang (2019) studied eight candidate working fluids R-123, R-245fa, R-114, R-236ea, R-236fa, RC318, R-227ea and R-1234yf with a low heat source grade of (100–150) °C. They concluded that under the given operating conditions, the heat source temperature and its allowable minimum temperature at outlet port influence the state for optimal turbine inlet condition. Further, the critical temperature of working fluid represents another factor which affects the optimal condition state.

Vankeirsbilck et al. (2011) compared the performance of the organic Rankine cycle with that of steam one. They concluded that the (ORC) can be operated on low-temperature heat sources grades with low to moderate evaporation pressure, and still achieve a better performance than that of a steam cycle. Molés et al. (2014) compared the performance of R-1233zd-E and R-1336mzz-Z, to R-245fa fluids in an (ORC). They concluded that R-1233zd-E requires 10.3% to 17.3% lower pump power and provides up to 10.6% higher cycle efficiency than R-245fa over the tested range of cycle conditions. They also postulated that the turbine size for R-1233zd-E would be about 7.5% to 10.2% larger than for R-245fa. More recently, Tarrad (2020) investigated the performance of a simple organic Rankine cycle (SORC) when circulated R-123, R-134a, R-290, R-245fa, R-1234ze-E, and R-1233zd-E fluids at low-temperature levels. He concluded that the thermal efficiencies of R-134a, R-123, R-245fa, R-1233zd-E, and R-1234ze-E were higher than that of R-290 by (10–14)%, (11–12)%, (9–12)%, (4–7)% and (1–3)% respectively. R-290 exhibited thermal efficiencies close to R-1233zd-E and R-1234ze-E in the superheat degree range of (5–15) °C. Hence, the hydrocarbon fluid R-290 is a suitable alternative candidate to the conventional fluids R-245fa and R-1233zd-E in the basic organic Rankine cycle (SORC) with a little more safety precautions.

In this work, the thermal performance of a compound regenerative organic Rankine cycle (CRORC) system was compared to that of the independent regenerative organic Rankine cycle (IRORC) system under the same operating

conditions. Four organic fluids, R-123, R-1233zd-E, R-245fa, and R600a were studied as candidate working fluids. Four fluid pairs were utilized to evaluate the thermal performance of the postulated system. A hypothetical organic Rankine cycle of nominal heat recovery of 50 kW was implemented for the evaluation of the cycle performance. The low-temperature waste heat source was suggested to be available at the range between 160 °C and 200 °C. Superheat degrees of (10–20) °C were assumed for both temperature levels of the cycle and no subcooled was utilized at the discharge ports of condensers of both mini-cycles.

Methodology

Organic Fluids

The critical point characteristics, pressure, and temperature play a significant role in the working fluids' selection philosophy. Further, the fluid has to possess attractive global warming potential (GWP), Ozone depletion potential (ODP), and favourable thermal properties. Four organics were selected as working fluids to be circulated in the suggested compound regenerative organic Rankine cycles (CRORC). Table 1 shows some of the physical, safety, and environmental characteristics of the selected working fluids.

Table 1. *Characteristics of Test Candidate Fluids*

Refrigerant	Chemical Formula	T _c (°C)	p _c (bar)	M _w (gr/mol)	T _{n,b} (°C)	Depletion		Safety Group*
						ODP	GWP	
R-123	CHCl ₂ CF ₃	183.68	36.618	152.93	27.82	0.02	77	B1
R-1233zd-E	CF ₃ CH=CHCl	166.45	36.237	130.496	18.26	0.00034	7	A1
R-245fa	CHF ₂ CH ₂ CF ₃	153.86	36.51	134.048	15.05	0	1030	B1
R-600a	CH(CH ₃) ₂ CH ₃	135.0	36.50	58.12	-12	0	3	A3

*ANSI/ASHRAE Standard 34 2016.

Selected thermodynamics properties of the test fluids are listed in Table 2 for both of the high-temperature and low-temperature cycles fluids.

Table 2a. *Thermodynamics Properties of the Candidate Working Fluid R-123 for the Higher Temperature Level Cycle*

Refrigerant	Pressure (bar)		Liquid Density (kg/m ³)		Liquid Enthalpy (kJ/kg)		Vapor Enthalpy (kJ/kg)	
	50 °C	150 °C	50 °C	150 °C	50 °C	150 °C	50 °C	150 °C
R-123	2.1246	20.987	1397.8	1036.8	251.06	367.1	411.50	461.05

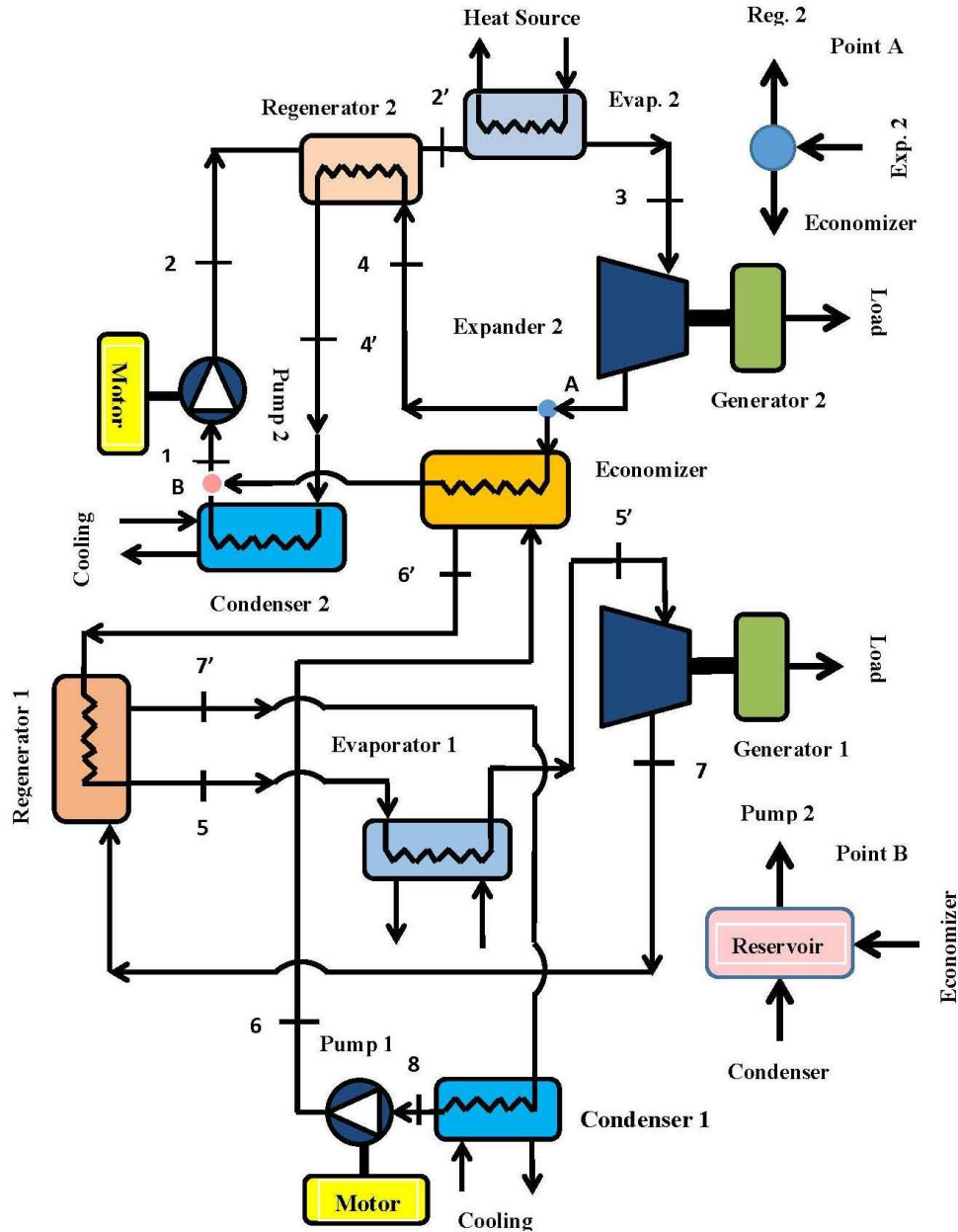
Table 2b. *Thermodynamics Properties of Working Fluids for the Low-Temperature Level Cycle*

Refrigerant	Pressure (bar)		Liquid Density (kg/m ³)		Liquid Enthalpy (kJ/kg)		Vapor Enthalpy (kJ/kg)	
	35 °C	130 °C	35 °C	130 °C	35 °C	130 °C	35 °C	130 °C
R-123	1.305	14.6	1437.7	1133	233.5	340	401	452.70
R-1233zd-E	1.831	19.081	1238	927	243.37	372.878	429.635	484.764
R-245fa	2.117	23.442	1311	940	245.81	390.39	430.08	487.699
R-600a	4.686	33.665	541.42	279.37	282.68	602.31	603.09	691.89

These fluids were selected according to their excellent thermal performance in organic Rankine cycles (ORC), Yuan and Zhang (2019), Vankeirsbilck et al. (2011), Molés et al. (2014), and Tarrad (2020).

Compound Cycle

Figure 1. Compound Cycle with Economizer Condenser

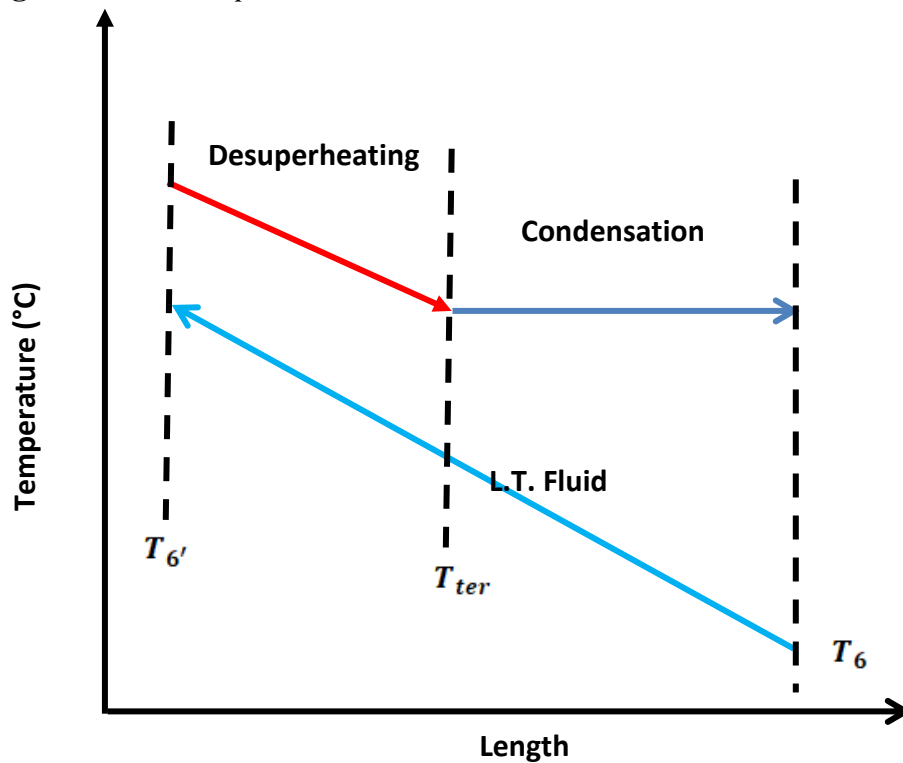


The arrangement of the postulated cycle is shown schematically in Figure 1, it consists of two regenerative cycles. The upper part of the system represents the high-temperature cycle which circulates R-123 at 150 °C and 50 °C evaporation

and condensation temperatures respectively. It utilizes a regenerator to capture the energy before leaving to the condensation unit and improves the thermal performance. The lower part of the compound cycle represents the low-temperature cycle where one of the R-123, R-245fa, R-1233zd-E, or R-600a fluid was circulated in the low-temperature level of 130 °C and 35°C evaporation and condensation temperatures respectively.

The two cycles are combined through the economizer which extracts the energy from R-123 vapor at the exit of the expander port (4) and heats the low-temperature fluid before passing through the regenerator at the lower part of the system. The suggested technology improves the thermal management of the cycle, it raises the temperature of low-temperature cycle fluid and minimizing the required heat absorbed at the lower part of the cycle. An 8% of R-123 mass flow rate of the high-temperature cycle fluid was extracted at point (A) and passed through the economizer. This amount of fluid bypass was inferred from keeping a constant terminal temperature difference between condensate and the low-temperature fluid at the exit side of the condensation zone of the condenser. This is shown schematically in Figure 2.

Figure 2. Fluid Temperature Variation in the Economizer



In the present work, a value of 2 °C was considered as a maximum terminal temperature difference (ΔT_{ter}) to ensure a complete condensation of the bypassed fluid amount in the economizer. Although using a lower (ΔT_{ter}) raises the low-temperature fluid to a higher energy level but it is not preferable since this will

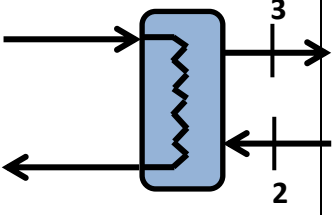
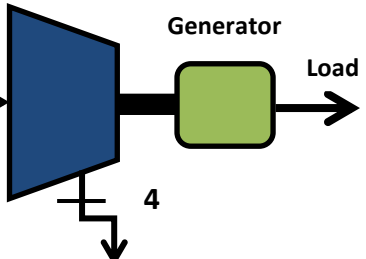
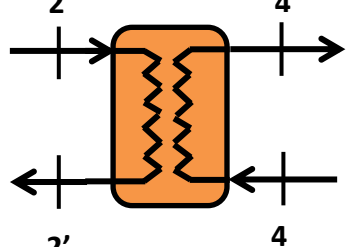
increase the surface area of the economizer which could lead to an economic issue problem.

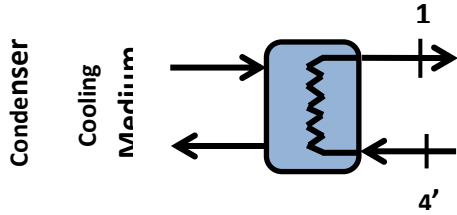
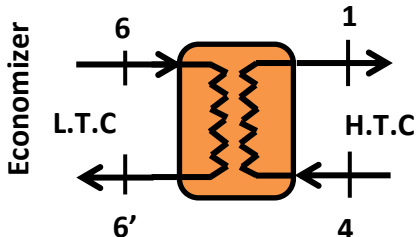
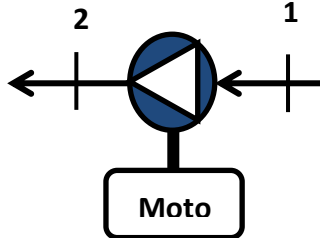
The remainder amount of flow rate accounts for 92% of total circulating fluid was passed through the regenerator (2) where it heats the R-123 fluid before entering the evaporator (2). The bypassed R-123 fluid was condensed in the economizer and discharged to the reservoir at point (B) and mixed with the condensed flow from the condenser (2) as shown in Figure 1. This technique allows for consuming energy at a low-temperature level and converts it to a useful one for electricity production.

Thermal Analysis

The thermal analysis of the compound cycle is presented in Table 3 for each of the cycle components in the high and low-temperature levels.

Table 3. Thermal Analysis of the Compound Regenerative Organic Rankine Cycle (CRORC)

Component	Analysis
<p>Evaporator</p> <p>Heat source</p> 	$\dot{Q}_{evap,H.T} = \dot{m}_{H.T} (h_3 - h_{2'}) \quad (1.a)$ $\dot{Q}_{evap,L.T} = \dot{m}_{L.T} (h_{5'} - h_5) \quad (1.b)$
<p>Ex pa nd er</p>  <p>Generator</p> <p>Load</p>	$\eta_{is,ex,H.T} = \frac{h_3 - h_4}{h_3 - h_{4,is}} \quad (2.a)$ $\eta_{is,ex,L.T} = \frac{h_{5'} - h_7}{h_{5'} - h_{7,is}} \quad (2.b)$ $\dot{W}_{ex,H.T} = \eta_{m,ex} \eta_{v,ex} \dot{m}_{H.T} (h_3 - h_4) \quad (3.a)$ $\dot{W}_{ex,L.T} = \eta_{m,ex} \eta_{v,ex} \dot{m}_{L.T} (h_{5'} - h_7) \quad (3.b)$
<p>Re ge ne rat</p> 	$\varepsilon = \frac{T_4 - T_{4'}}{T_4 - T_2} \quad (4.a)$ $\varepsilon = \frac{T_7 - T_{7'}}{T_7 - T_{6'}} \quad (4.b)$ $h_{2'} = h_2 + h_4 - h_{4'} \quad (5.a)$ $h_5 = h_{6'} + h_7 - h_{7'} \quad (5.b)$

Component	Analysis
	$\dot{Q}_{cond,H.T} = 0.92 \dot{m}_{H.T} (h_{4'} - h_1) \quad (6.a)$ $\dot{Q}_{cond,L.T} = \dot{m}_{L.T} (h_{7'} - h_8) \quad (6.b)$
	$\dot{Q}_{Econ} = 0.08 \dot{m}_{H.T} (h_4 - h_1) \quad (7)$ $h_{6'} = h_6 + \frac{\dot{Q}_{Econ}}{\dot{m}_{L.T}} \quad (8)$
	$\eta_{is,p,H.T} = \frac{h_{2,is} - h_1}{h_2 - h_1} \quad (9.a)$ $\eta_{is,p,L.T} = \frac{h_{6,is} - h_8}{h_6 - h_8} \quad (9.b)$ $\dot{W}_{p,H.T} = \dot{m}_{H.T} (h_1 - h_2) / \eta_{m,p} \quad (10.a)$ $\dot{W}_{p,L.T} = \dot{m}_{L.T} (h_6 - h_8) / \eta_{m,p} \quad (10.b)$

The first law of thermodynamics efficiency is defined as:

$$\eta_{net} = \frac{\dot{W}_{ex} - \dot{W}_p}{\dot{Q}_{evap}} \quad (11)$$

Hence, the compound cycle net thermal efficiency is estimated from:

$$\eta_{net,com} = \frac{(\dot{W}_{ex,H.T} + \dot{W}_{ex,L.T}) - (\dot{W}_{p,H.T} + \dot{W}_{p,L.T})}{\dot{Q}_{evap,H.T} + \dot{Q}_{evap,L.T}} \quad (12)$$

The corresponding net thermal efficiency for the two independent cycles is calculated by:

$$\eta_{net,ind} = \frac{(\dot{W}_{ex,H.T} + \dot{W}_{ex,f}) - (\dot{W}_{p,H.T} + \dot{W}_{p,f})}{\dot{Q}_{evap,H.T} + \dot{Q}_{evap,f}} \quad (13)$$

The subscription (f) refers to the working fluid which is circulating in the lower temperature cycle. This includes R-123, R-245fa, R-1233zd-E, and R-600a

at evaporation and condensation temperatures of 130 °C and 35 °C respectively. The high-temperature cycle corresponds to the R-123 working fluid at evaporation and condensation temperatures of 150 °C and 50 °C respectively. The parameter $\eta_{net,ind}$ is the mean value of the net thermal efficiency when these cycles operate independently at the two temperature levels.

The mass flow rate of the circulated fluid was calculated for the hypothetical cycles of the total 50 kW nominal evaporation load, for a mini-cycle of the (CRORC) and independent systems, it corresponds to:

$$\dot{m} = \frac{25}{(h_{g,evap} - h_x)} \quad (14)$$

In this expression, it has been assumed that each mini-cycle of the (CRORC) and independent systems possesses half of the total nominal heat load. The $(h_{g,evap})$ refers to the vapor enthalpy at the operating evaporator saturation temperature, Table 2. The enthalpy (h_x) corresponds to that at the pump discharge side, it is equal to (h_2) and (h_6) for the high and low-temperature mini-cycles respectively for the compound system. The same mass flow rates were circulated in both of the (CRORC) and (IRORC) systems.

$$\dot{Q}_{evap,t} = \dot{Q}_{evap} + \dot{Q}_{sup} \quad (15)$$

Table 4 illustrates the numerical values of the efficiencies of the expander and pump and the effectiveness of the regenerators.

Table 4. The Numerical Values of Performance Parameters Utilized at the Present Work

Parameter	Magnitude
Expander isentropic efficiency, $\eta_{is,ex}$	85%
Expander volumetric efficiency, $\eta_{v,ex}$	85%
Expander mechanical efficiency, $\eta_{m,ex}$	90%
Pump isentropic efficiency, $\eta_{is,p}$	85%
Pump mechanical efficiency, $\eta_{m,p}$	80%
Regenerator effectiveness, ε	80%

The evaluation of the performance comparison between different test fluids under similar operating conditions was based on the discrepancy percentage defined as:

$$\beta_\phi = \frac{\phi_n - \phi_{ref}}{\phi_n} \times 100 \quad (16)$$

Here, the subscriptions (n) and (ref) refer to the compared fluid and reference fluid respectively. The parameter (ϕ) refers to the required characteristic variable

for comparison such as \dot{W}_{pump} , \dot{W}_{exp} , \dot{Q}_{evap} , and η_{net} . This expression is valid for comparison of the performance of the same fluid at different operating conditions such as volumetric efficiency or evaporation temperature change. The comparison of the compound regenerative organic Rankine cycle (CRORC) system and the independent regenerative organic Rankine cycle (IRORC) system performance parameters were deduced from:

$$\zeta_{\phi} = \frac{\phi_{com} - \phi_{ind}}{\phi_{com}} \times 100 \quad (17)$$

The parameter (ϕ) has the same definitions as those in Eq. (16). Equation (17) is valid for all of the compared parameters, \dot{W}_{pump} , \dot{W}_{exp} , and η_{net} except for the consumed energy one (\dot{Q}_{evap}) which was inverted as:

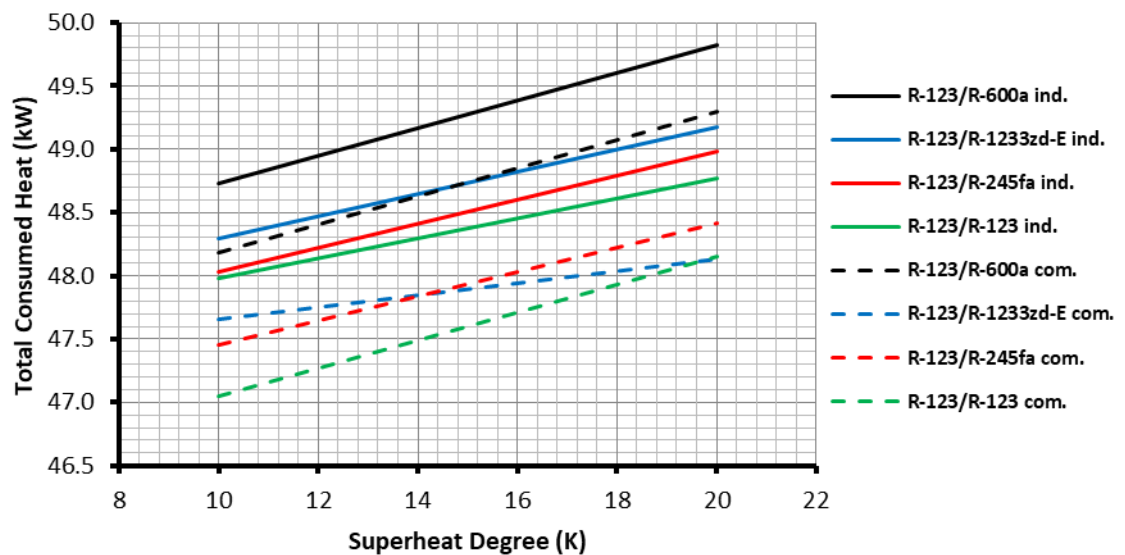
$$\zeta_{\dot{Q}_{evap}} = \frac{\dot{Q}_{evap,ind} - \dot{Q}_{evap,com}}{\dot{Q}_{evap,ind}} \times 100 \quad (18)$$

Results and Discussion

Consumed Energy

Figure 3 illustrates a comparison of the total consumed heat rate between the compound and independent cycle systems.

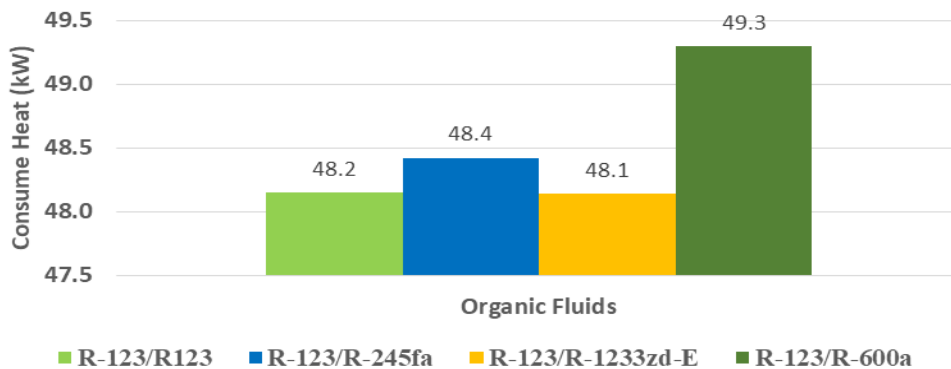
Figure 3. A Comparison of Consumed Heat Load for the (CRORC) and (IRORC) Systems



The results indicated that the (IRORC) independent cycle system needed more energy consumption than that of the compound system for all fluid

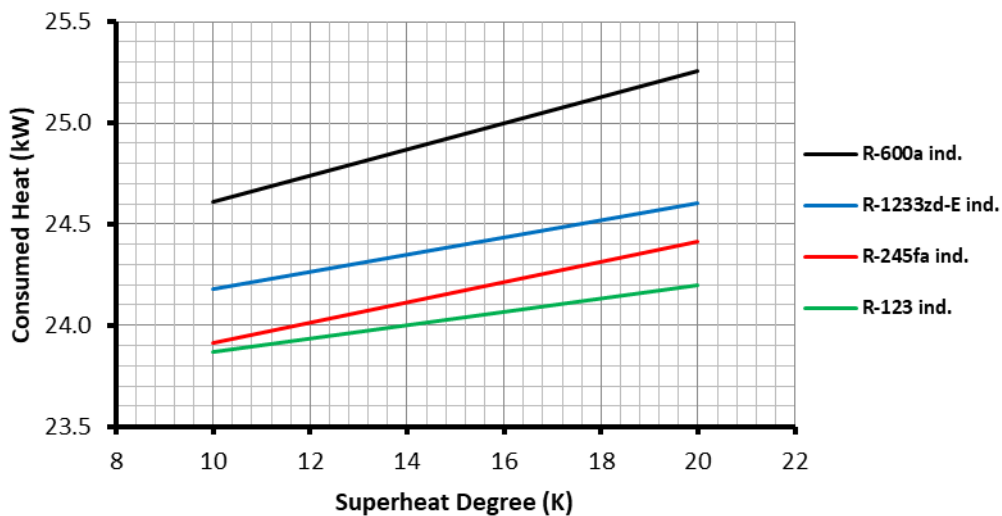
combinations, the high and low-temperature cycles. The R-123/R-600a and R-123/R-123 systems consumed the higher and lower energy respectively than other fluid combinations for both compound and independent cycle systems. For the independent system, the R-123/R-600a, R-123/R-245fa, and R-123/R-1233zd-E systems showed higher energy extractions than that of R-123/R-123 by (1.5–2)%, 1% and 0.5% respectively. The corresponding numerical values of energy consumption discrepancy from that of the R-123/R-123 system for the R-123/R-600a, R-123/R-245fa, and R-123/R-1233zd-E systems were 2.5%, 1%, and 1% respectively. Figure 4 depicts a comparison of the total consumed energy for both of the high and low-temperature levels of the compound system at a superheat degree of 20 °C.

Figure 4. A Comparison of the Consumed Heat of the Compound System for Different Fluid Combinations at a Superheat Degree of (20) °C



The consumed energy for the independent system was higher than that of the compound system by the range of (1–2)% for the test fluid combinations and operating conditions.

Figure 5. Comparison of Consumed Heat Load at the Simple Independent Low-Temperature Cycle Version



At the low-temperature cycle of (IRORC) operating conditions, the R-600a and R-123 cycles showed higher and lower consumed energy respectively than other examined fluids, Figure 5. R-600a, R-1233zd-E and R-245fa energy consumptions were higher than that of the R-123 value by (3–4)%, (1.3–1.7)% and within 0.5% respectively. The corresponding values of the consumed energy for the low-temperature cycles were 5%, (2–2.5)% and about 2% higher than that of the R-123 fluid for the R-600a, R-1233zd-E and R-245fa respectively.

The gradients of the consumed energy to the superheat degree for the R-123 and R-1233zd-E cycles were the lower among other working fluids. Hence, the superheat degree has less influence on the consumed energy for R-123 and R-1233zd-E, whereas R-600a showed the higher gradient and R-245fa exhibited a moderate one.

Thermal Efficiency

Figure 6 illustrates the net thermal efficiency comparison for both of the compound and independent systems when circulating different combinations of working fluids. The general trend of the results revealed that the compound cycle system achieved higher thermal efficiencies than those of the independent one. The compound system provided a thermal efficiency enhancement when compared to the independent system within the range of 2%. The R-123/R-1233zd-E pair showed lower thermal efficiency among the other examined fluid pairs and operating conditions.

Figure 6. A Comparison of the Net Cycle Thermal Efficiency for the Two-Cycle Systems

Figure 6a. R-600a and R-1233zd-E Low-Temperature Cycle Fluids

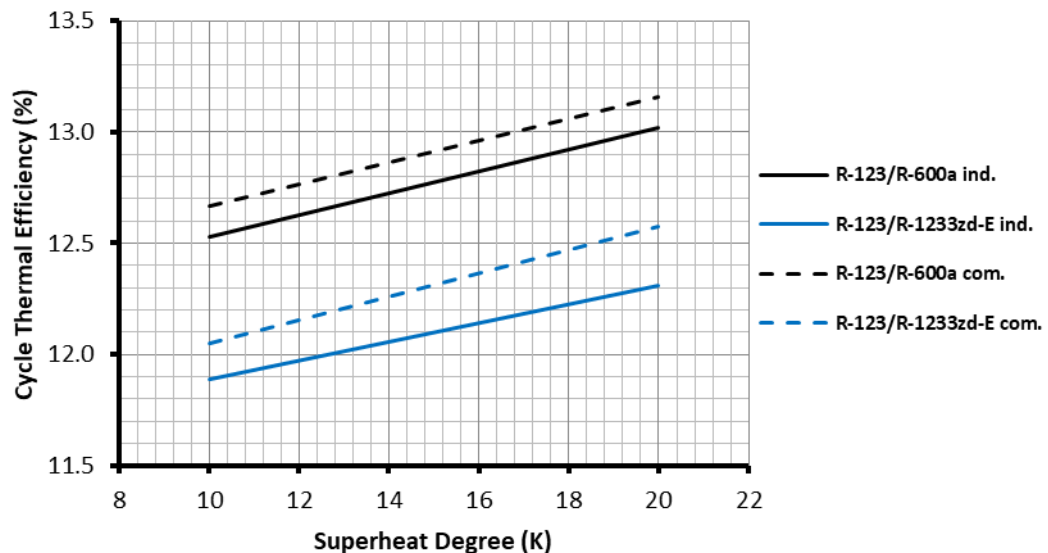
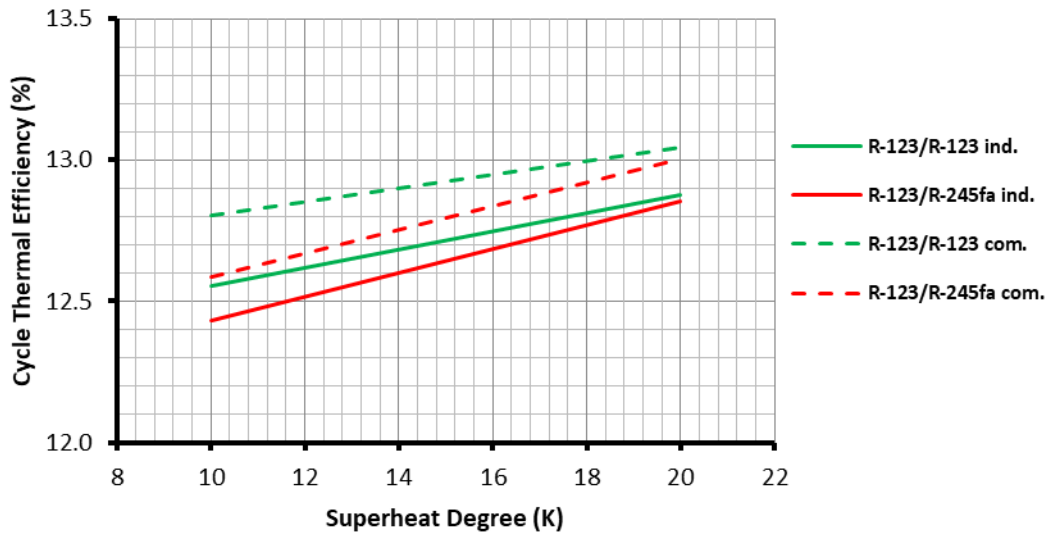


Figure 6b. *R-245fa and R-123 Low-Temperature Cycle Fluids*

The (CRORC) system of R-123/R600a, R-123/R-123, and R-123/R-245fa fluid pairs exhibited higher thermal efficiency than that of R-123/R-1233zd-E pair by (4.5–6)%, (4–6)% and (3–4)% respectively. The corresponding discrepancies for these pairs in the independent system were higher than that of the R-123/R-1233zd-E pair by (5–5.5)%, (4–5)%, and (4–5)% respectively.

Figure 7 illustrates the net thermal efficiency of the compound system at the examined operating conditions and superheat degrees. The net thermal efficiency of the compound (CRORC) system fell in the range between 12% and 13% for all of the examined operating conditions.

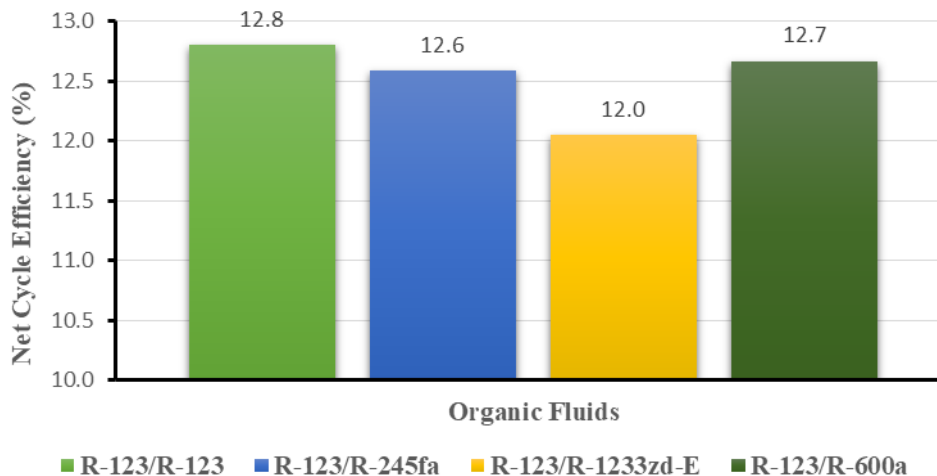
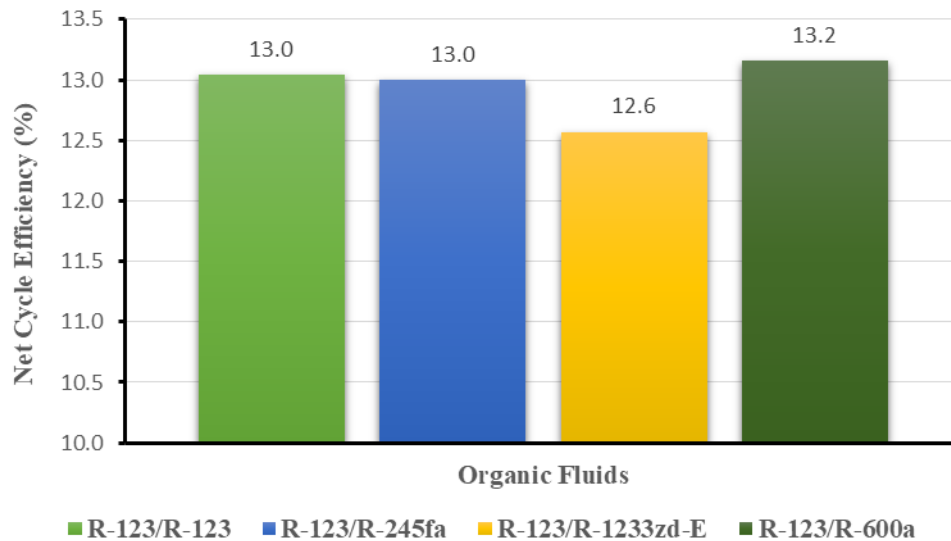
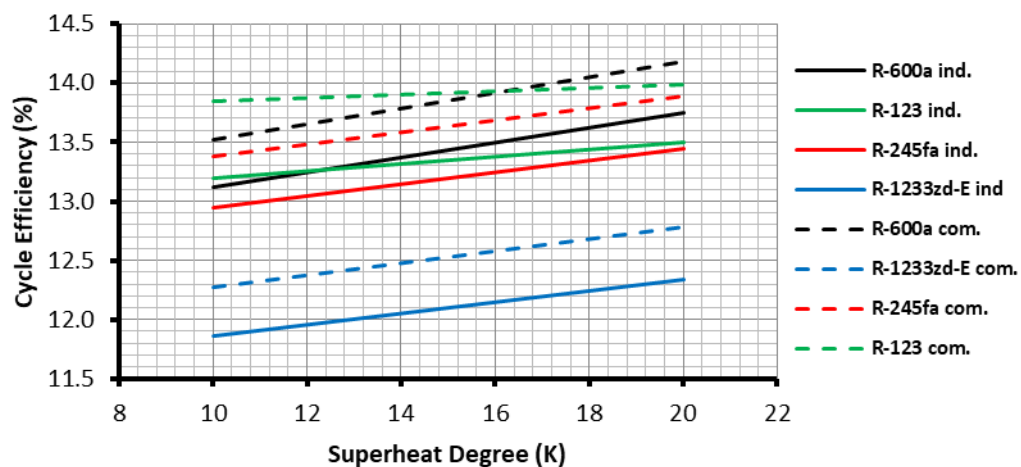
Figure 7. *A Comparison of the Cycle Net Thermal Efficiency for the Compound (CRORC) System Arrangement***Figure 7a.** $\Delta T_{sup} = 10^\circ\text{C}$ 

Figure 7b. $\Delta T_{sup} = 20\text{ }^{\circ}\text{C}$ 

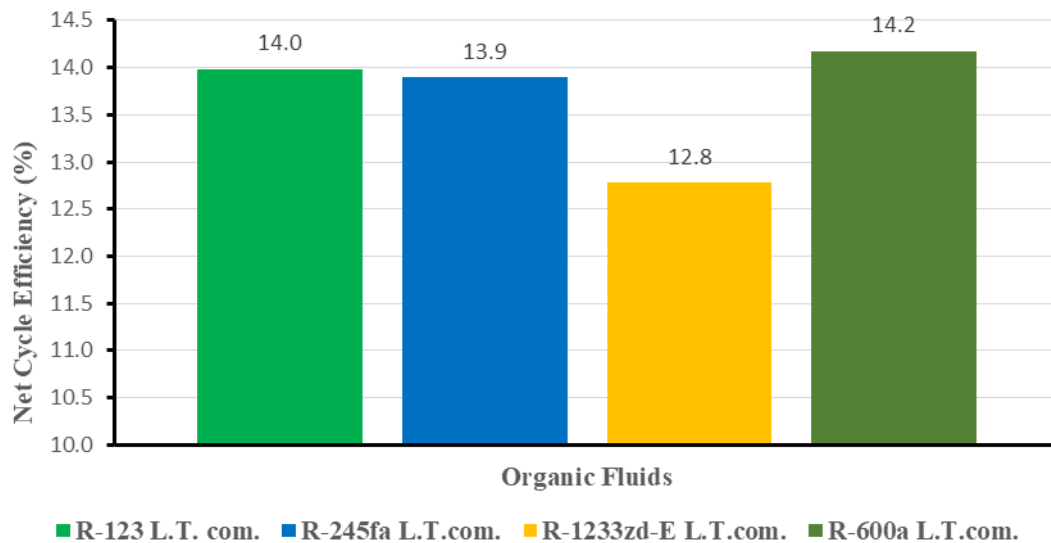
The fluid pairs of R-123/R600a, R-123/R-123, and R-123/R-245fa exhibited close figures of the thermal efficiency, the maximum discrepancy between them fell within 1.5%. The data showed that increasing the superheat degree from 10 °C to 20 °C has enhanced the thermal efficiency of the compound (CRORC) system by (2–4)%. The corresponding figures for the 20 °C of the independent (IRORC) system fell within the range of (2.5–4)% as they were compared to the results at 10 °C.

The utilization of the economizer has improved the thermal performance of the low-temperature cycle by minimizing the amount of energy required to run the evaporator. The energy consumption at the low-temperature cycle was reduced by (3–5)%. The thermal efficiency of the low-temperature cycle as compared to that of the independent system is shown in Figure 8.

Figure 8. A Comparison of Net Cycle Efficiency of the Independent and Compound Systems for the Low-Temperature Part

The thermal efficiency of the low-temperature cycle of the (CRORC) showed an enhancement of about (3–5)% as compared to the low-temperature of the independent cycle of the (IRORC) system. The R-1233zd-E fluid exhibited the lower value of the thermal efficiency among the other examined fluids at the low-temperature mini-cycle whereas the R-600a cycle produced the highest thermal efficiency. The numerical values of the thermal efficiency discrepancies for the R-600a, R-245fa, and R-123 were (9–11)%, 8%, and (8–11)% respectively when compared to that of the R-1233zd-E low-temperature mini-cycle of the (CRORC) efficiency. The thermal efficiency of the low-temperature mini-cycle of the (CRORC) system approached a value of 14% at 20 °C superheat degree, Figure 9, whereas the R-1233zd-E cycle achieved (12.8)% at the same operating conditions.

Figure 9. Cycle Net Thermal Efficiency for the Low-Temperature Mini-Cycle of the Compound System at (20) °C Superheat Degree



Conclusions

A compound cycle was suggested and thermally analyzed to improve the energy management for the case where different temperature levels of waste energy are available in the industrial site. This technique of the (CRORC) has minimized the total energy consumption by (3–5)% for the low-temperature level. This accounts for 2% reduction of total consumed energy when compared to independent cycles (IRORC) operation. This technique showed that the first law of thermodynamics efficiency was improved by (3–5)% for the low-temperature mini-cycle. The numerical values of the mini-cycle low-temperature of the (CRORC) thermal efficiency for the R-600a, R-245fa, and R-123 working fluids were (9–11)%, 8%, and (8–11)% respectively higher than that of the R-1233zd-E one.

The (CRORC) system of R-123/R600a, R-123/R-123, and R-123/R-245fa fluid pairs exhibited higher thermal efficiency than that of R-123/R-1233zd-E pair

by (4.5–6)%, (4–6)% and (3–4)% respectively. The corresponding discrepancies for these pairs in the independent system were higher than that of the R-123/R-1233zd-E pair by (5–5.5)%, (4–5)%, and (4–5)% respectively. The net thermal efficiency of the compound (CRORC) system fell in the range (12–13)% and the low-temperature mini-cycle had a range of (12–14)% for all of the examined operating conditions. Increasing the superheat degree from 10 °C to 20 °C has enhanced the thermal efficiency of the compound (CRORC) system by (2–4)%. The corresponding figures for the 20 °C of the independent (IRORC) system fell within the range of (2.5–4)% as they were compared to the results at 10 °C.

Acknowledgments

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Nomenclature

Parameter	Definition
h	Fluid specific enthalpy, (kJ/kg)
M_w	Fluid molecular weight, kg/kmol
\dot{m}	Fluid mass flow rate, (kg/s)
P	Fluid working pressure, (bar)
\dot{Q}	Heat transfer rate, (kW)
s	Fluid specific entropy, (kJ/kg)
T	Fluid temperature, (°C)
\dot{W}	Power, (kW)

Subscription

Parameter	Definition
c	Critical point
com	Compound
$cond$	Condenser
$evap$	Evaporator
ex	Expander
g	Gas condition
$H.T$	High-temperature side
i	Inlet side
ind	Independent
is	Isentropic
$L.T$	Low-temperature side
n	Fluid, normal point

<i>net</i>	Net value
<i>p</i>	Feed pump
<i>ref</i>	Reference fluid
<i>sup</i>	Superheated vapor
<i>t</i>	Total
<i>ter</i>	Terminal
<i>v</i>	Volumetric

Greek Letter

β	Deviation percentage, (%)
ε	Heat exchanger effectiveness, (%)
ζ	Deviation, (%)
η	Cycle thermal efficiency, (%)
ϕ	Characteristic parameter

Abbreviations

Parameter	Definition
<i>CRORC</i>	Compound Regenerative Organic Rankine Cycle
<i>GWP</i>	Global Warming Potential
<i>IRORC</i>	Independent Regenerative Organic Rankine Cycle
<i>ODP</i>	Ozone Depletion Potential
<i>ORC</i>	Organic Rankine Cycle

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What 5G has been and what should 5G+ be?

By Zoran Bojkovic^{*}, Dragorad Milovanovic[±], Tulsi Pawan Fowdur[‡] &
Mussawir Ahmad Hosany⁺

In this work we aim to provide a comprehensive summary of the most inspiring aspects of 5G mobile networks. In addition, we present the latest findings on the promising 6G technology towards a world of fully digital connectivity. The key determinants are extreme system performance and combinations of requirements for new use cases. We study new performance targets beyond 5G in two stages: 5G+ evolution and new 6G step. Relevant technologies considered too immature for 5G or outside the defined scope are outlined. To justify our vision of future mobile networks, we point out the need for closer collaborations of academia, standardizing bodies, industrial organizations and governments. The contribution strategy is gradual evolution and performance enhancement of mobile communications. Finally, we identify challenges and directions on network technology roadmap toward 6G.

Keywords: wireless communication, mobile broadband, low-latency communication, 5G network, 3GPP, 6G vision

Introduction

The new 5G generation of mobile telecommunications systems meet the ITU-R IMT-2020 (International Mobile Telecommunications-2020) requirements by supporting the Internet Protocol (IP) network with higher data rates, larger number of connections, and considerable lower latency than previous generations (Bojkovic et al. 2020, Milovanovic et al. 2019, Milovanovic and Bojkovic 2019). Over the past years, the first complete set of global technical standards has enabled a basic commercial deployment of 5G mobile networks. Consumers and businesses are looking to a 5G wireless connection to enable faster downlink/uplink speeds and high quality of service (QoS) that's secure and reliable in new vertical applications of Smart transportation ITS, industrial IoT, eHealth, Smart cities. The academic community as well as industrial organizations are already turning their considerations towards the next generation of mobile communication termed as 6G (Andrews et al. 2014, Tripathi and Reed 2020, David and Berndt 2018).

With a view of achieving enhanced performance of 5G+ core services we identified three methods in this work. Mobile broad bandwidth and low latency (mBBL) service will provide a high-quality experience (QoE) in typical applications of mobile augmented/virtual reality (AR/VR) and holographic

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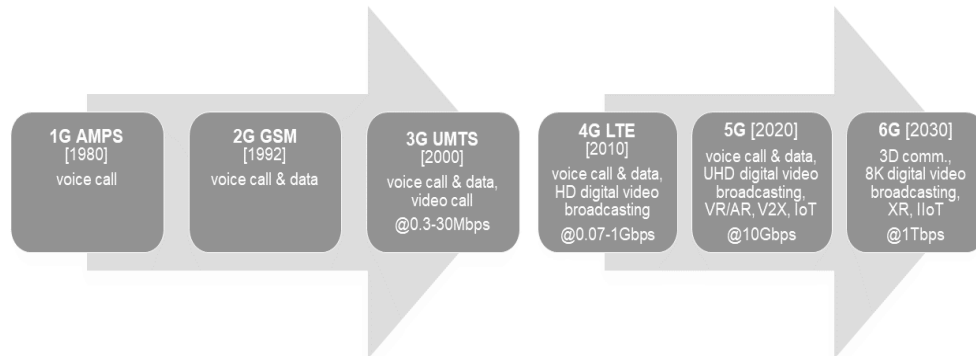
teleconferencing. Next, massive broadband width machine type (mBBMT) service enhances 5G mobile broadband and machine communication in typical application of tactile IoT. And finally, massive low-latency machine type (mLLMT) service enhances ultra-reliable and low-latency communication in typical application of large scale industrial IoT (Dang et al. 2020, Saad et al. 2020).

Objective of the paper is to review evolution of mobile network starts from the first 1G to newest 5G generation. Next, the main objective in collaborations of industry experts, academia and international organizations is to identify challenges and directions on network technology roadmap toward 6G. We study new performance targets beyond 5G in two stages: 5G+ evolution and new 6G step. The key determinants are extreme system performance and combinations of requirements for new use cases in terms of functionalities and quality of experience. Paving the way towards 6G, relevant technologies considered too immature for 5G or which are outside the defined scope will be included. Finally, we study three technology milestones for the upcoming years.

Background

Every one to two years there are new 3rd Generation Partnership Project (3GPP) releases leading to a constant evolution of cellular communication systems. A new generation is derived from one of the releases in general every 10 years or decade. Technology research at the conceptual level along with a vision of a typical use case and deployment scenario is brought about at the start of every 10 year cycle. The ultimate goal of commercial network deployment is achieved by following established research procedures, development of specifications and finally prototyping of the systems. It is expected that significant improvements will be achieved with the design of a new generation standard. The evolution of mobile network starts with the first analog mobile standards termed as 1G, then by the second generation (2G) standard termed as GSM (Global System for Mobile Telecommunications), followed by UMTS (Universal Mobile Telecommunication Systems) which is the technology for the third generation (3G), then LTE (Long-Term Evolution) which makes up the fourth generation (4G), and finally the current generation which is 5G as shown in Figure 1. The future or post 5G generation is termed as 6G. The implementation of 6G systems expected to start between 2027 and 2030. Larger spectral and energy efficiencies as well as data rates, lesser latency and improved security, as well as enhanced quality of service (QoS) are some basic issues that need to be addressed in beyond 5G+, system to make the transition from 5G. Toward 6G systems, all the potential key performance indicators (KPIs) must be attained by proceeding from the evolution of 5G systems. 6G communication is still in its infancy and research activities on 6G are in their initial stages. Several studies will be initiated globally on the standardization of 6G as from 2020 (ITU-T 2019, Posio 2020, 3GPP Technical Specification Group Services and System Aspects 2020).

Figure 1. Development of Data Rate and Application of Mobile Wireless Networks through Decades from 1980 to 2030 Years



Increased in spectral and energy efficiencies as well as network reliability and reduction in communication delays are all the goals set for a successful 5G communication network. It employs the microwave spectrum in the range 3.3-4.3 GHz as well as the mmWave band increasing in such a manner data rates up to 10 Gbps. It should be noted that BDMA (Beam division multiple access) and FBMC (Filter bank multicarrier) are used, together with many technologies integrated into 5G with the final objective to advance the characteristics of a network. The following 5G components have been implemented with a view to enhance user experience: Massive MIMO (multiple-input and multiple-output) systems to increase spectral efficiency, Software defined networks (SDN) to provide flexible connections, information content networking (ICN) to reduce network traffic and network slicing for fast deployment.

5G proposes three major scenarios in its communication domain and these are enhanced mobile broadband (eMBB), ultra-reliable and low latency communications (uRLLC) and massive type communications (mMTC). In order to enable various types of communication links, there are many protocols that have been implemented in the 5G standard. There are two reasons for this: the first one is supply, because same techniques still require experimental verification as well as test in practical situation. Secondly, from the demand point of view, advanced communication technologies employing different services and devices, despite that are not fully recognized as being important. Since it is difficult to find solution for all related problems, 5G is presently viewed as just an initial phase of deployment in the process of interconnection of user devices. Since limitation of radio coverage in service areas does not exist in 5G global standard, all user devices can be interconnected from any part of the globe. Therefore, research beyond 5G will aim to remove the differences between the definition and realization surpassing the existing vision and requirements (Posio 2020).

Presently the deployment of 5G standards for cellular networks is being considered and both the academic community as well industry are turning their attention to what comes next. In practice, it takes around ten years to design, implement and deploy a novel cellular networking standard. There this is the perfect time to research promising areas and novel directions for the next decade thereby laying the foundations for a possible 6G communication standard for

cellular networks. In transition to 5G, the main innovation from the physical layer is simultaneously support for variety of applications and services with different system data rates, delays and reliability requirements. This novelty has been possible by the OFDM (orthogonal frequency-division multiplexing) technology as well as by the concept of network slicing and massive MIMO systems that make use of very large antenna arrays at the base stations (Tripathi and Reed 2020).

5G+ Technology Roadmap

In order to design, implement and deploy the 5G technology it is imperative to have the collaborations among various industry experts, academia and international organizations that regulate standards. The main objective of such collaborations is to identify challenges and directions for cellular network technologies thereby, flagging the way for providing massive connectivity for wireless communications. Software defined (SDN) and network function virtualization (NFV) frameworks have to be with distributed systems software to enable all 5G+ systems. Other hand of systems are end-user integration, security, spectral and energy co-efficiency, maintaining service quality, faults tolerance of any kind. Some drastic upgrade of the whole communication needs to happen by this year 2020, in order to support the forecasted growth. It is imperative that industry for future networks participate in 5G and beyond technology roadmap activity.

The 3rd Generation Partnership Project (3GPP) is a consortium of standards organizations with technology roadmap of protocols for mobile telecommunications. 3GPP system provides Releases with a stable platform to researchers and developers with a view to implement features at a given instant and then allow for the addition of new functionality in subsequent Releases. The TR 21.900 Release provides mechanisms create and maintain specifications. 5G implementation so far (Release 15) are for public consumer type services. 5G Release 16 with focus on industry vertical being finalized only now (June 2020 with 3-month delay from March 2020). 5G Release 17 is scheduled for freeze Sep. 2021 and delivery in Dec. 2021. Work on 5G Release 18 starts in Sept. 2020. 6G Release 20 is expected around 2025 (3GPP Technical Specification Group Services and System Aspects 2020).

- **Phase 1** (3GPP Release 15 TR21.915) work began in June 2016 and was completed in September 2018. The NR sub system is presently being deployes commercially and it focuses on the eMBB use case.
- **Phase 2** (3GPP Release 16 TR21.916) is a major release for the project, because it will bring the specification organization's IMT-2020 RIT/SRIT submission (to ITU-R WP 5D) for a complete 3GPP 5G system. Release 16 has been put on hold in March 2020 with a targeted date of June 2020, when complete 5G standards are published.
- **Phase 3** (3GPP Release 17 TR21.917) focuses mainly on the improvements of a 5G+ system which already started in December 2019 and scheduled

for delivery in Dec. 2022. Regarding the architectural system of 5G, 3GPP provides Release 17 and beyond which has as objective to enhance support of IIoT (Industrial internet of Things) and convergence from wireless or wired users. Also, the Release 17 and beyond will have to improve support for multicast and broadcast architecture, proximity services, enhance provision of multi-access edge computing, and enhance care of network automation. With regard to the Radio Access Network (RAN) the community of 3GPP, in June 2019, identified many core research areas to be considered in Release 17. These areas are given as follows:

1. NR-Light: To enable lightweight communications for industrial sensors and similar applications.
2. IIoT and MIMO improvements.
3. Sidelink enhancements for both V2X (Vehicle-to-everything) and public safety.
4. Provision and support to enhance coverage.
5. Extension of 5G NR to operate in frequencies beyond 52 GHz to be included in Release 18. Deadline for Release 18 Stage 1 not yet decided, possibly December 2020 or later.

The 5G has been deployed with a view to provide drastic increase of wireless data traffic and support of other usage scenarios. Also, 5G+ and 6G technologies are anticipated to lengthen 5G competencies. There are many strict requirements that need to be met for providing high figures of merit such as increased bit rates (up to Tbps) and lower delays – such as pervasive edge intelligence, ultra-massive machine-type communication, holographic rendering and high precision communications. These strict requirements take the dimension of energy efficiency, intelligence, spectral efficiency, security, secrecy and privacy. Machine learning techniques such as deep and reinforcement learning are applied in the 5G technology as specific artificial intelligence approaches with a view to plan, schedule, represent knowledge and provide optimization. This enables to enhance user experiences and optimize networks more efficiently as well as provide high quality software applications. For instance, there are many data-demanding applications such as massive as well as Industrial IoT (IIoT), automatic robotic platforms including control, sensors and actuators, as well as the integration to other techniques into cyber-physical systems will impose new performance requirements (Dang et al. 2020).

Performance Indicators towards 6G

5G+ will be implemented with the main objective of reducing latency among user devices and enhancing reliability for services that extend beyond edge cloud or private environments. This objective is presently inspiring because of the absence of an advanced transport network protocol architecture. Heterogeneous network segments together with edge fabric may also integrate the 5G+

environment and this will facilitate configuration and control of new applications and services. It is envisaged that 5G+ will provide data rates in excess of hundreds of Mbps with delays of less than 1 ms while simultaneously assuming connections to billions of devices. In order to radically change the living and working styles of mobile users services such as entertainment, e-Health, Industrial IoT, smart cities and smart transportation have to be incorporated in the verticals of 5G+.

The 6G technology is expected to provide much wider application scenarios than what 5G+ will do. It is important to have backward compatibility with the 5G primary services such as eMBB, mMTC and uRLLC. 6G will also include novel services such as holographic communication, personal monitoring, drone taxi, Internet of robots, etc. One of the most significant applications is virtual and augmented reality (AR/VR). On the other hand, holographic communication (HC) is considered as a high throughput requirement of 6G. In the near future, media interaction will be transformed from the current plane multimedia to high-fidelity AR/VR and to wireless holographic communication.

As shown in Table 1, new performance targets beyond 5G will be met in two stages: 5G+ evolution, and new 6G step.

Table 1. Performance Indicators 5G vs. 5G+ vs. 6G

Performance measure	5G	5G+	6G
Peak data rate	10-20 Gbps	100 Gbps	1 Tbps
Per-user data rate	1 Gbps	10 Gbps	>10 Gbps
Traffic density	10 Tb/s/km ²		>100 Tb/s/km ²
Connection density	10 ⁶ /km ²		10 ⁷ /km ²
Delay	ms level	1 ms	<1 ms
Mobility	350 km/h		>1000 km/h
Spectrum efficiency	3-5x relative to 4G		>3x relative to 5G
Energy efficiency	1000x relative to 4G		>10x relative to 5G
Coverage percent	70%	80%	>90%
Reliability	99.9%	99.99%	>99.999%

Source: Dang et al. 2020.

The energy efficiency, density and data rate is projected to increase tenfold in 6G. Spectrum efficiency and mobility are expected to be enhanced threefold. Moreover, the latency in 6G will be brought down further to below 5 ms. Rise from the current 70 percent to 99 percent is expected for the coverage percentage. Presently the reliability in 5G is 99.9% and this will increase to 99.999% in 6G. Positioning error will be reduced from the current meter range to the centimeter range.

The key 6G determinants are extreme system performance and combinations of requirements for new use cases (Figure 2, Table 2).

Figure 2. Evolution of 5G Primary Service Classes to Extreme 6G Performances for Specific Use Cases and Combinations of Requirements for New Use Cases

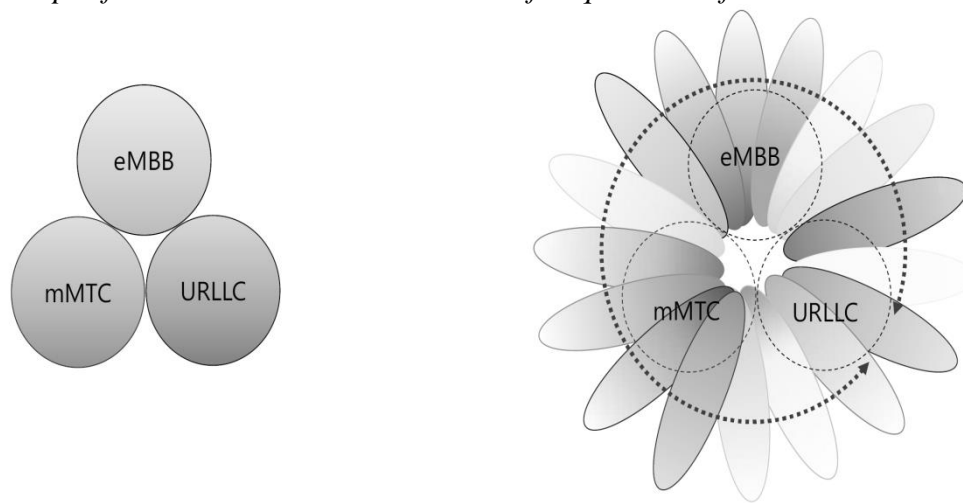


Table 2. Application Types 5G vs. 5G+ vs. 6G

	5G	5G+	6G
Applications	eMBB URLLS mMTC	Reliable eMBB URLLC mMTC Hybrid (URLLC+eMBB)	MBRLLC mURLLC HCS (human-centric services) MPS (multi-purpose services)

Source: Tripathi and Reed 2020.

Most of the use cases in 6G are evolving from the emerging 5G system based applications in terms of functionalities and quality of experience. However, 6G new use cases will combine experience sharing AR/VR and telepresence applications, increasing per-user data rate from 100 Mbps to 1 Gbps, peak data rate from 20 Gbps to 1 Tbps, and decreasing air-interface latency from 1 ms to 100 micros. Remote control applications of eHealth, Industry 4.0 and unmanned mobility will be combined in new use cases with reliability increase from 99.999% to 99.99999%, spectrum efficiency 5x from 5G, as well as vehicle speed from 500 kmph to 1000 kmph. Connecting everything applications of pervasive connectivity with increase spectrum efficiency 5x from 5G, per-user data from 100 Mbps to 1 Gbps, number devices from 10^6 pkm² to 10^7 pkm², as well as energy efficiency 10-100x from 5G.

Paving the Way towards 6G

The immature features that 5G could not support will now be included in 6G with the relevant technologies. Focusing on the physical layer of a 6G technology one can find many research opportunities in order to increase further the data rates offered by the 5G. For example, using carrier frequencies above 40 GHz, including even the terahertz bands. The high carrier frequency band will increase the spectral

channels with bandwidths of several gigahertz to tens of GHz possible. Another opportunity that 6G can be accommodated is the provision of low-resolution multiple antenna architectures with digital beamforming to support multiple users thereby providing higher flexibility than what was provided by 5G. The third opportunity is to re-investigate large bandwidths in the context of signal processing models. Robotics is a characteristic use case of signal processing and will be found in the factory in the future. Another key research direction for 6G is machine-learning toolset. It has been already envisaged that 6G will be implemented with Artificial Intelligence algorithms at all levels. The departure point in the implementation process would be from the network orchestration and management to coding and signal processing in the physical layer. Furthermore, in the 6G implementation there would be the manipulation of smart structures and data mining in the network as well as device level for service-based communications. A 6G driving trends and enabling technologies are shown in Table 3.

Table 3. 6G Driven by Innovative Applications and Enabling Technologies

Driving applications	Driving trends	Enabling technologies
Combine experience sharing (multisensory XR, telepresence)	More bits, spectrum, reliability	Radio spectrum above 6 GHz
Remote control and autonomous systems	Spectral and energy efficiency	Transceivers with integrated frequency bands
Connecting everything	From areal to volumetric	Integrate terrestrial, airborne and satellite networks
	Convergence of communication, sensing, control and computing	Energy transfer and harvesting
		Emergence of smart surfaces and environments

Due to the unprecedented increase in the number of innovative applications it is imperative to have a new cellular generation. 6G is no exception: In fact, it will be created with a set of novel and exciting applications and technological trends that will shape its performance targets while drastically redefining the core 5G services.

At the time when 6G systems will be made commercially available there will be further performance enhancements and new use cases added in the applications and services. To differentiate between the services provided by 5G and 6G there are three popular 5G use cases that will be provided as evolutionary examples. These are haptic communication for virtual and augmented reality (VR/AR), massive IoT integrated Smart City, and automation as well as manufacturing (Hu et al. 2020, Chen et al. 2018).

- Haptic communication improves the touch sense of the outdated audio-visual communication over the Internet and is the key to unravel the prospective of VR/AR. This is of importance because a process of medical remote surgery requires ultra-sensitive delay of less than 1 ms which is not yet available in upcoming systems (Bastug et al. 2017, Elbamby et al. 2018, Park and Bennis 2018).

- In the 5G system IoT has been implemented to make smart city a reality. In a smart city the major constituents such as public utilities, healthcare and monitoring are exclusively clever and considered discretely. 6G will adopt the universal approach in a fundamental way for a Smart city as compared to 5G.
- In the industrial sector for any country it is vital to incorporate large number of robots into automation and transportation. These evolving concepts enhance the Industry 4.0 by exploiting mobile, analytics and cloud. 6G will fully support the industrial sector with massive IoT and AI capabilities.

6G will transport massive data with advanced computation capability and in this context AI (artificial intelligence) techniques will be implemented in all applications and services. Latest research has also geared towards edge cycling Fog radio access networking (Fog-RAN) and it has been shown that contents can be brought closer to user equipment (UEs), allowing for significant reduction in latency and power consumption.

Conclusions

The 5G system has been successfully standardized and it is being deployed worldwide. So, it is time to move on. The 6G infrastructure should fill the gap between 2020+ societal and business demands and what 5G can support. Research on 6G is in the phase of study. We study new performance targets beyond 5G in two stages: 5G+ evolution and new 6G step. We learnt from the study three technology milestones for the upcoming years and these are described as follows:

- **Short-term evolution.** The deployment of 5G network deployment on a worldwide basis continues and all applications and services are available in large cities. To exploit the 5G evolution many vertical solutions are being considered. The 6G community has started to collect feedback from the 5G one.
- **Medium-term evolution.** A common discussion platform for frequency bands is considered for 6G and the architecture as well as the core technologies for smart networks are being developed. There is increased share of satellite communications. 5G business and vertical segments are well developed. The core technologies for 6G are selected and tested (RF, mm-wave, THz, optical). Also, 6G will employ extensive and advanced signal processing algorithms and applied AI/ML are being evaluated and compared. Testing and evaluations of the component networks of 6G are being worked out. Integration work towards experimental 6G testbed is underway.
- **Long-term evolution.** Advanced technologies for smart networks (SN) are considered. Cybersecurity and AI/ML in SN and 6G verticals are being exploited. Advanced radio technologies and DSP techniques are considered

in 6G. Land and satellite networks are being integrated. Companies and business size in the field are increased significantly.

To justify our vision of future 5G+ networks, we point out the need for closer connection of academia, standardizing bodies, industrial organizations and governments in demand-oriented roadmap. Also, the advancement of wireless communications is highly restricted by basic sciences, especially mathematics and physics. The contribution strategy is gradual evolution and performance enhancement mechanisms based on investment in more spectral and hardware/software resources of mobile communications networks.

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Agile-Stage-Gate Approach: Exploratory Research on the Structure, Roles, and Responsibilities

By Ali Eljayar^{} & Jeff S Busch[±]*

One of the most prominent methodologies gaining recognition in recent years is the Agile-Stage-Gate approach. The relatively new hybrid model is a combination of the Stage-Gate and the Agile-Scrum models. Several companies already using the Stage-Gate process have recently adopted the Agile-Stage-Gate approach to improve product development and project management. However, each of these companies has added their adjustments and modifications to the new approach in order to accommodate their specialized needs and to achieve the goals that are unique to their company. Therefore, no fixed structure or standardized features have been explicitly assigned to this hybrid approach. Instead, each company has added on different features and manipulated the new approach to fit whatever needs arise from moment to moment. This ambiguity leads to the question of whether the structure, roles, and responsibilities of this new approach can be defined and if so, how these clear and consistent definitions can improve productivity, efficiency, communication and market response time. The purpose of this study is to explore the structure, roles, and responsibilities within this new approach and to identify patterns that emerge during the product development and project management processes. The research questions presented were administered and examined through a qualitative survey. Fifty-two complete responses were collected from experienced individuals who have varying degrees of experience with the Agile-Stage-Gate approach. These findings revealed many similarities and differences between the structure, roles, and responsibilities of this approach, which were also dependent on the product and project type being considered. The most apparent similarities between roles and responsibilities were found in the case of software products and new product development projects. The Agile-Stage-Gate approach has also had a significant and undeniable impact on team communication and performance and was shown to improve overall quality and productivity.

Keywords: agile, stage-gate, customer, scrum, sprint, hybrid, ideation, combination products, backlog, retrospective

Introduction

Background of the Agile-Stage-Gate Approach Research

The nature of new product development is characterized by complexity and uncertainty in most cases. Companies are racing to be the most innovative and to react quickly to market changes. The unpredictable nature of this process places manufacturers under highly-competitive pressure. Organizations are required to keep their product development systems up to date and maintain a level of innovation in order to retain high customer satisfaction. Each organization must

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also determine how to introduce their new product to the market in a relatively short time while staying within their predetermined budget and scope. The complexity and uncertainty associated with product development make it difficult for companies to deliver the product on schedule and within budget, all while maintaining high levels of quality. Therefore, companies must prioritize creativity in order to continuously adapt to the rapidly changing industry environment by both modifying and transforming their way of thinking and doing things. This openness to transformation will allow companies to remain adaptive, instead of solely predictive.

One of the most noticeable methodologies that has gained recognition in recent years is the Agile-Stage-Gate hybrid approach. Some companies have adopted this hybrid approach to reduce time-to-market and to respond to changing customer requirements more quickly. The Agile-Stage-Gate approach is a combination of the Stage-Gate model and the Agile-Scrum model, which will be discussed in detail later. The framework of the Stage-Gate model is used to manage New Product Development by following a sequence process and a plan-driven focus, whereas agile models (such as Scrum, used widely in the software industry) focus more on customer feedback and short-term outcomes that require immediate attention.

Statement of the Problem

Several companies that already use the Stage-Gate process have recently adopted the Agile-Stage-Gate approach for new product development. However, each of these companies has also added adjustments and modifications to the hybrid model in order to accommodate their system needs and to achieve their ultimate goals. Therefore, there are no fixed structures or standardized features explicitly assigned to this hybrid approach. Instead, each company adds on different features and manipulates the hybrid model to fit their immediate needs. This research therefore focuses on defining the structures and features of this new approach as well as identifying the roles and responsibilities associated with it in order to discover consistent definitions that lead to improved productivity, efficiency, communication and market response time.

Purpose of the Study

Many authors have already discussed different aspects of the Agile-Stage-Gate approach. However, few have outlined the fluid changes in roles, responsibilities, and structure associated with the hybrid model and the patterns that emerge when applied to different products and projects. This paper aims to explore the current version of the Agile-Stage-Gate approach when developing different products (such as software, hardware, and combination products), as well as different project types (such as New Product Development, R&D, and projects that provide a service to customers). This study will focus on companies that implement Stage-Gate first and then adopt the new approach. This research will also identify the recurring structures, roles, and responsibilities that define this hybrid approach.

Research Questions

This project will address five research questions (listed below) to outline exactly what will be covered in the research and how the purpose of this study will be fulfilled.

RQ1: What is the structure of the Agile-Stage-Gate approach when applied to the different products (software, hardware, and a combination of both) and within different projects (New Product Development, R&D, and a project that provide a service to customers)?

RQ2: What team roles are instituted by companies that use the Agile-Stage-Gate approach?

RQ3: What are the responsibilities of each team role when the Agile-Stage-Gate approach is in use?

RQ4: What effect does the Agile-Stage-Gate model have on project team quality, specifically pertaining to 1) communication and 2) coordination?

RQ5: What is the long-term strategy and vision of each company that applies the Agile-Stage-Gate approach?

Assumptions and Limitations

Although this paper will provide a brief overview of both Agile and Stage-Gate models separately (including the structure, roles, and responsibilities of each), the main focus will remain on the structure, roles, and responsibilities associated with the Agile-Stage-Gate hybrid approach. In addition, the associated benefits and improvements produced by adopting the hybrid model will remain a focal point. The aim is not to focus on the details of each separate model, nor how each stage or sprint is functioning individually. Instead, the organization and communication of team dynamics will be examined, along with how each different type of team operates within the project team as a whole and within the rest of the organization.

Literature Review

In this section, established information from current and previous research will be presented regarding the Stage-Gate, Agile-Scrum and Agile-Stage-Gate project management methods, which is the main focus of this paper. This section also will provide extensive information from different industry papers about what has already been examined regarding the Agile-Stage-Gate approach in terms of the structures, roles, and responsibilities of this approach, along with project team organization and resources for each implemented method.

Stage-Gate Models

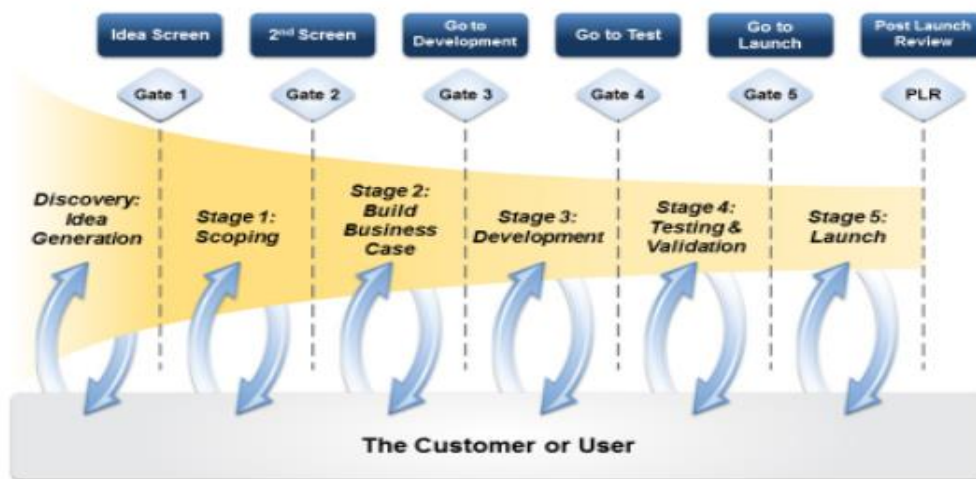
The Structure and Principle of Stage-Gate Models

The Stage-Gate approach was adopted by industries world-wide around 1990. Since then, it has become a well-known model used to manage New Product

Development. The model is designed to move a new product from idea to launch (Cooper 1990). It aims to drive new product projects to the market, both quickly and effectively. The model's structure is made up of stages and gates, with each stage composed of a set of prescribed cross-functional and parallel activities (following a typical 5-stage/5-gate process, as shown in Figure 1).

In each stage, the project team members execute tasks and take action to move the project forward. The necessary pieces of information related to each stage are compiled and monitored closely in order to reduce risk and uncertainty (Cooper 2006). A gate follows each stage, at which time a Go/Kill decision is made. Each of these gates also serves as a checkpoint and a function of quality control to ensure that the project is executed correctly. Over the past few decades, Stage-Gate models have evolved from a simple linear process to a more dynamic and integrated process that can quickly respond to market changes and customer needs (White 2008).

Figure 1. *Flow of a Typical Stage-Gate Model*



Source: Cooper 2010.

The phase of **Discovery** is designed to discover business opportunities and provide new ideas.

1. **Scoping:** The primary purpose of this stage is to build a robust understanding of the project and define the general scope of the product (Cooper 2015, 2010).
2. **Building a business case:** The selected ideas are tested and developed in regards to technical, financial, market and operational aspects. This phase aims to ensure that the product is feasible and corresponds to the market requirements. A more detailed and in-depth investigation takes place, justifying the project and planning a robust business case (Cooper 2015, 2010).
3. **Development:** At this point, a specific criterion for the new product must be met in order to move into this stage. The project team develops a

detailed design of the new product and the result of this stage is a lab-tested product (Cooper 2015, 2010).

4. **Testing and validating:** A complete paradigm is tested and validated in this phase to determine if there are any required changes before moving on to the last stage. Marketing and branding validation is also checked and tested (Cooper 2015, 2010).
5. **Launch:** In this stage, the commercialization process begins with a full operation of production. The market and distribution plans are executed and the project team is now ready to launch the product (Cooper 2015, 2010).
6. **Gates:** Before each stage, there is a gate where a Go/Kill and prioritization decision is made. These gates serve as quality control checkpoints to ensure that the product has successfully met the six proven criteria, which include 1) Strategic Fit, 2) Product and Competitive advantage, 3) Market Attractiveness, 4) Technical Feasibility, 5) Synergies/Core Competencies and 6) Financial Reward. By applying these criteria, any mediocre projects are culled out at each gate. These gates are usually monitored and controlled by senior managers from different functions. They are called the gatekeepers and they own the resources required by the project leader and team for the next stage (Cooper 2015, 2010).

Stage-Gate Roles and Responsibilities

Project team members in all organizations and projects need to thoroughly understand their roles and responsibilities in order to complete their specific tasks and participate effectively in the project development. Roles and responsibilities are an imperative component of the Stage-Gate model and are considered to be one of the five primary artifacts of the Stage-Gate approach. In his book "Winning at new products", Dr. Cooper, who introduced the Stage-Gate model for the first time in 1986, outlines the specific roles that are vital to the success of the Stage-Gate model. These include Project Team Members, a Project Leader, a Project Manager (optional), Gatekeepers, a Process Manager, and an Executive Sponsor (Cooper 2011).

Project Team is made of members from different departments (such as technical, marketing, operations, and sales) who come together to create a cross-functional team. Usually, the team starts the project and is accountable for accomplishing their individual tasks, and the project deliverables within the designated time frame.

Project Leader is a member of the Project Team and plays a critical part in terms of leading by promoting the project, managing resources, and handling the external interfaces of the project with senior management.

Project Manager is an optional role for the smaller project because the Project Leader is also able to act as Manager. The responsibility of the Project Manager is to ensure that the project functions well, and the project team utilizes the project management tools and methods appropriately.

Gatekeepers form a cross-functional group that is usually made up of senior management. This group owns the resources for the project and makes the Go/Kill and prioritization decisions.

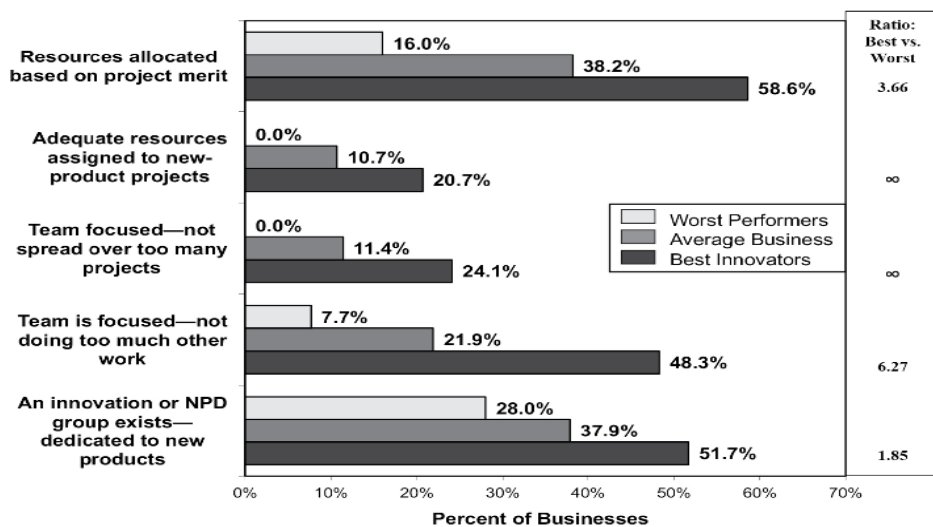
Process Manager is assigned by 72.2% of manufacturing companies to supervise the gating system and to ensure that the Project Teams understand and maintain the process and its practices (Cooper 2011). The Process Manager may also facilitate gate meetings, coach teams, and provide training.

Executive Sponsor role is activated for large projects and is usually a member of the senior management. This role serves to mentor and guide the Project Team and advise the Project Leader. The Executive Sponsor can also overlap roles by simultaneously acting as a Gatekeeper.

Project Team Organization and Resources

Providing the Project Team with sufficient resources and the right organizational structure will strongly influence project outcomes. Having dedicated resources that are available for full-time use is one of the most critical factors for producing practical product innovation, as seen in Figure 2, 58.6% of the best innovators have dedicated resources for product development, while 48.3% have a focused cross-functional group (made up of marketing, operations, and R&D departments). Overall, a focused Project Team that makes use of available resources has been proven to have a strong positive impact on performance (Cooper 2011).

Figure 2. *Impact of Project Team Focus and Dedicated Resources on Performance*



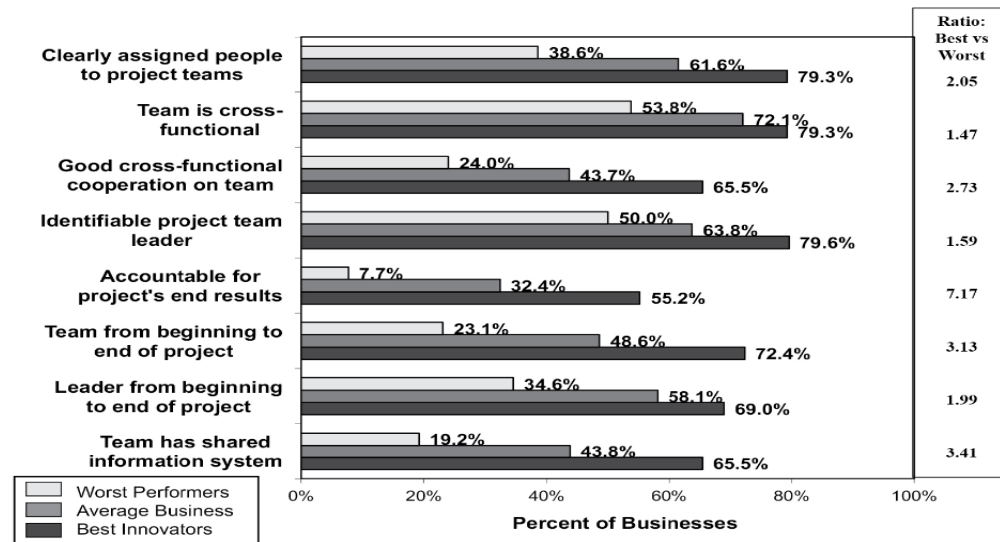
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ce: Cooper 2011.

The organizational structure and composition of the Project Team dramatically determine the success of product innovation, which includes the identification of roles, responsibilities, and assigned tasks. The product innovation process is not the mission of only one division; it is multidisciplinary, cross-functional work. As shown in Figure 3, more than 79% of the best innovators have a cross-functional

team with clearly assigned individuals and an identifiable Project Leader (Cooper 2011).

Figure 3. *Impact of New Product Development on Innovation and Performance in Project Teams*



Source: Cooper 2011.

Agile Project Management

New management techniques have emerged in the latter part of the 20th century as a response to the internet revolution and its associated technologies. This evolution raised the criteria for successful projects. Companies are now required to not only produce high-quality products but to produce them rapidly. This evolving global economy is characterized by 1) a high degree of uncertainty in business projects, 2) an increase in customer desire for speed, and 3) a quick response to market changes (White 2008).

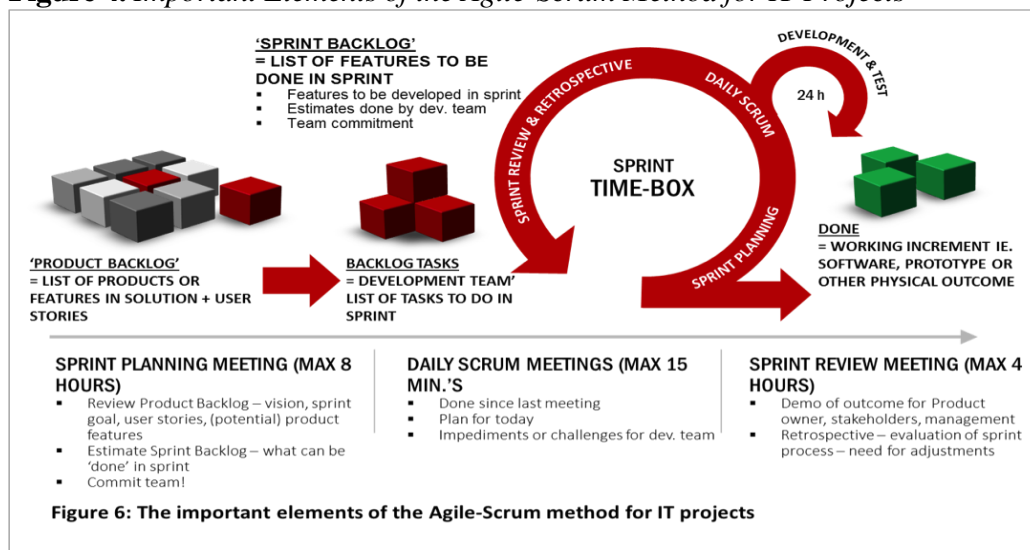
Organizations and project managers must be equipped with persuasive techniques (such as Agile project management) in order to have the ability to adjust quickly and respond to business needs. Agile project management is based on the twelve principles from The Agile Manifesto that was first introduced in 2001. Agile project development relies heavily on the concept of self-organized teams, who work closely with customers and collaborate between multiple functions throughout many iterations. The focus is on the adaption of changes as the project progresses (Sliger 2011). Agile project management aims to help companies maneuver the reality of continuous change by allowing the project team to work closely with customers, define their requirements, and incorporate changes throughout the project life cycle (Sliger 2011). Agile project management is also considered to be a better way to oversee the older problems associated with traditional project management techniques (such as Waterfall) when managing large IT projects (Cooper and Sommer 2016a).

Applying Agile Methods through Scrum

In 1981, Ikujiro Nonaka and Hirotaka Takeuchi first identified the Scrum approach in the Harvard Business Review in a piece titled, "The New New Product Development Game" (Cooper and Sommer 2016a). The authors utilized the sport of rugby as a metaphor to show the effectiveness of self-organized teams in innovative product development and delivery. Jeff Sutherland, Ken Schwaber, and Mike Beedle applied this method to their field of software development at Easel Corporation in 1993, which became the Scrum framework (Sliger 2011).

Scrum is a dominant agile methodology and is intended to guide teams in the form of iterative and incremental delivery of a product. 42% of organizations use Scrum, while another 54% of companies combine it with other techniques (Scrum Alliance 2015). The Scrum approach focuses on the use of an experimental process that allows the team to respond rapidly, effectively, and efficiently to market changes and customer needs. The Scrum framework is based on the idea that fixed timeframes and costs will best control project requirements. In contrast, traditional project management methods use fixed requirements to control time and cost. The Scrum framework consists of Sprints, Product backlog, Sprint Backlog, Sprint Planning meeting, Backlog Tasks, and Daily Scrum Meeting, as shown in Figure 4 (Vedsmand et al. 2016).

Figure 4. Important Elements of the Agile-Scrum Method for IT Projects



Source: Vedsmand et al. 2016.

Sprints are the basic units of Scrum methodology. Each is a time-box of continuous development and test iteration, usually lasting 1–4 weeks. The Sprint can be seen as a container for other Scrum activities, such as the Daily Scrum daily meeting, Sprint Review, Sprint Planning, and Sprint Retrospective. In the case of a big project and a larger team, many sprints can be run simultaneously or consecutively (Schwaber and Sutherland 2017, Sliger 2011, Schwaber 2004).

Product Backlog acts as the overall vision and map for product production. The Product Backlog lists all the product features, functions, and requirements

necessary to create a finished product. It is managed by the product owner and continuously updated based on product progress and customer needs. The Product Backlog is prioritized based on the development strategy with the essential items listed first (Schwaber and Sutherland 2017, Sliger 2011, Schwaber 2004).

Sprint Backlog is a list of chosen items from the Product Backlog that are developed in each Sprint. The development team agrees on how they will deliver the requirements for the current Sprint during the Sprint Planning Meeting. The Sprint Backlog provides a thorough overview of the work that has been done, along with the remaining work required for completion (Schwaber and Sutherland 2017, Sliger 2011, Schwaber 2004).

Sprint Planning Meeting is an event where the Scrum team determines how the team will accomplish the Sprint Backlog tasks. In this meeting, the Scrum team selects items from the Product Backlog that will be achieved in the subsequent Sprint. The team will also agree upon the definition of "done" and define the Sprint goal (Schwaber and Sutherland 2017, Sliger 2011, Cooper and Sommer 2016a).

Daily Scrum Meeting is a daily 15-minute meeting facilitated by the Scrum Master. At this meeting, the development team discusses what they accomplished in the last 24 hours, what they will do today, and what challenges they are facing. The daily Scrum meeting is meant to improve communication, remove obstacles, share knowledge, and make sound decisions (Schwaber and Sutherland 2017, Sliger 2011, Cooper and Sommer 2016a).

Sprint Review is conducted at the end of every Sprint when the delivered product increment is presented to management and customers. The outcome of the Sprint Review is a working increment, such as a prototype or a piece of functioning software. The Product Backlog is also revised, and the team provides their input for the following Sprint (Schwaber and Sutherland 2017, Sliger 2011, Cooper and Sommer 2016a).

Sprint Retrospective is often a three-hour meeting for a one-month Sprint. The goal of the Sprint Retrospective is to evaluate the process and implement the lessons learned into the next Sprint. The Scrum Master is responsible for facilitating the meeting and ensures that the Sprint process is adequately adhered to (Schwaber and Sutherland 2017, Sliger 2011, Cooper and Sommer 2016a).

Roles and Responsibilities of the Agile-Scrum Method

The Scrum team is a multi-functional and self-organized team. The team should have all the competencies needed to achieve all tasks for the product increment. The Agile-Scrum framework has only three roles: Scrum Master, Product Owner, and Development Team (Sliger 2011, Schwaber and Sutherland 2017).

Product Owner owns the Product Backlog and is responsible for communicating the project vision to the team. The Owner focuses on

maximizing the product value and ensures everything is completed during the Sprint. The Product Owner is also responsible for prioritizing and managing the Product Backlog (Sliger 2011, Schwaber and Sutherland 2017).

Scrum Master is the keeper of the Scrum's rules and process. The Scrum Master usually facilitates team communication and ensures that the team operates according to the Scrum rules. The Scrum Master also assists the team in removing any external obstacles and negotiates with stakeholders who are external to the team (Sliger 2011, Schwaber and Sutherland 2017).

Development Team typically consists of 3–9 people who are responsible for delivering the product requirements that were agreed upon beforehand at the end of each Sprint. The team is self-organized and co-located, meaning that they work in the same physical environment. The whole team is accountable for the Sprint, meaning that they collaborate and help each other to solve problems (Sliger 2011, Schwaber and Sutherland 2017).

Integration of the Agile Method into the Stage-Gate Process

The Drive to Adopt the Agile-Stage-Gate Model

As a result of the internal and external challenges faced by the manufacturers in new product development, the Agile-Stage-Gate has become a practical solution to overcome these challenges. The high demand from the customers to shorten the time-to-market, respond faster, and increase the flexibility during product development also revealed the need for this new approach. Manufacturers have recognized that the traditional methods are no longer feasible to deal with challenges evolving from new complexity. Thus, a new approach and mindset are needed to overcome these challenges (Cooper and Sommer 2016a, Sommer et al. 2015). In recent years, various manufacturing companies (especially Business-To-Business organizations) have adopted the Agile-Stage-Gate hybrid method in order to respond to market changes in the industry quickly (Cooper and Sommer 2016a, Sommer et al. 2015).

Combining the Agile-Scrum Approach with Traditional Gating Processes

The discussion on whether or not the Stage-Gate and Agile methods can be successfully combined has already begun. Since identifying successful examples of this combination is imperative for the future of the hybrid model, a few IT companies have begun to implement the agile methods into their existing Stage-Gate process. For example, Karlström and Runeson (2005, 2006) studied three large scale European technology companies, namely Vodafone, Ericsson, and ABB (Karlström and Runeson 2005, 2006). These three firms each integrated the Agile approach into the Stage-Gate process for their IT projects. The results of this study revealed that the two approaches integrated seamlessly. Also, the new approach improved the internal team communication, planning, and customer feedback on the early stages, thus proving that the two models were compatible (Karlström and Runeson 2005, 2006).

Applying the Agile-Stage-Gate Approach to Physical Products

Although there is a shortage of research that examines the application of the Agile-Stage-Gate approach for the development of physical products, one Danish study chose to focus on five manufacturing companies that integrated Agile into their Stage-Gate system (Cooper and Sommer 2016a, 2016b, Sommer et al. 2015). The results of this study positively indicated that the Agile-Stage-Gate method could be successfully implemented for physical products from an operational standpoint. The study specifically revealed that the hybrid approach improved efficiency, and reduced work effort by 25% per project and reduced rework by nearly 20% (Cooper and Sommer 2016b). These five firms also reported that the new approach increases the visibility of the processes overall, improves team ownership, and increases motivation. In addition, they noted a significant improvement in the communication within the team and in the coordination across the entire organization (Cooper and Sommer 2016b).

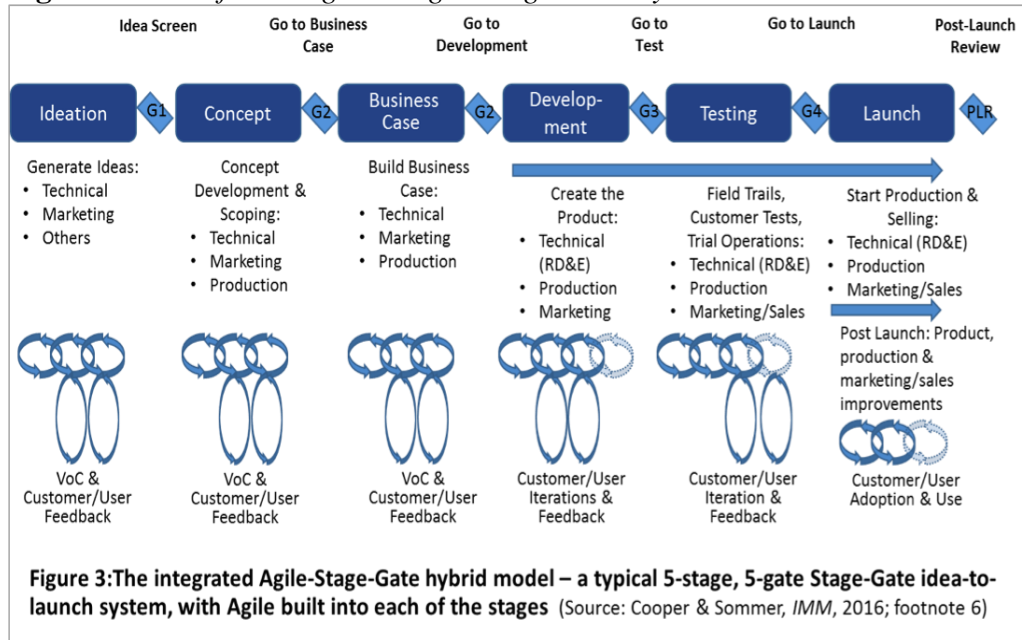
Previous Instances of Main Research Questions Addressed by Other Researchers

This section examines what research has been conducted previously regarding the five main research questions outlined in this paper. The previous research available is somewhat limited, hence the purpose of the in-depth analysis presented in this project. However, all available information found in the literature has been gathered and outlined below.

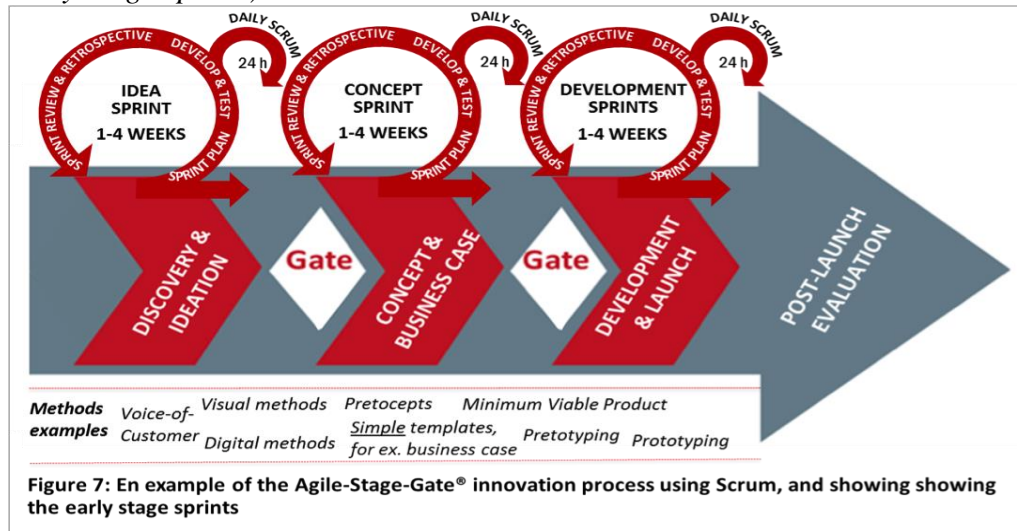
RQ1 - What is the structure of the Agile-Stage-Gate approach when managing different products (e.g., software, hardware, or a combination of both) and different projects (e.g., new product development, R&D, or customer service)?

Combining Agile and Stage-Gate methods does not necessarily mean abandoning the individualized nature of the Stage-Gate approach. Instead, the Agile-Scrum features can be integrated into the Stage-Gate model to maximize the benefits of both (Sommer et al. 2015). The Agile-Stage-Gate is most often implemented during the Development and Testing stages. However, it has been found that Agile-Stage-Gate functions effectively in all stages of the project, as shown in Figure 5 (Vedsmand et al. 2016).

For instance, one case study conducted by Dr. Robert Cooper on a global company called Thermo-Valves (a disguised name) revealed that the Agile-Stage-Gate approach should be applied across every stage in order to achieve the maximum benefit (Cooper and Sommer 2016a). Another example comes from a GEMBA Innovation company in Denmark that applied the Agile-Stage-Gate approach to their version of the ideation and concept stages to great success (Cooper and Sommer 2016a). Other early adopters of the Agile-Stage-Gate approach reported that it could be used in the early stages, but that some adjustment and modification is still needed (Cooper and Sommer 2016a). Figure 6 outlines the structure required to effectively integrate the Agile-Scrum model into the earlier stages of development (Vedsmand et al. 2016).

Figure 5. Flow of an Integrated Agile-Stage-Gate Hybrid Model

Source: <https://innovationmanagement.se/2016/08/09/integrating-agile-with-stage-gate/>.

Figure 6. Example of the Agile-Stage-Gate Approach using Scrum (Including Early-Stage Sprints)

Source: <https://innovationmanagement.se/2016/08/09/integrating-agile-with-stage-gate/>.

Although manufacturing companies still tend to modify the Agile-Stage-Gate hybrid to fit their needs and maximize their values, most of the Agile-Scrum features that are used in the IT industry (such as the Sprint, Product Backlog, Sprint Review and Daily Scrum meeting) are still applied when using the Agile-Stage-Gate model. The Agile-Stage-Gate approach introduces a brand new way of thinking and planning for manufacturing organizations. For instance, when using the hybrid model, the project team can implement a plan-on-the-fly approach so

that they only need to expend energy on what is mandatory in the current Sprint or Stage (Cooper and Sommer 2016a).

Unlike the planning process involved in traditional project management methods, the Agile-Stage-Gate approach allows the Project Team to plan on the fly for each Sprint in real-time and respond more dynamically to product improvement. The hybrid model also enables the team to work more closely with the customer and receive their feedback on the incremental release of the designs and prototypes. This increased access to the customer is crucial since the customer's voice acts as the primary driver for improvement, allowing the team to move product development in the right direction. In the Agile-Stage-Gate model, time-boxed **Sprints** are still applied and last from 2 to 4 weeks, although they may last longer for big or more complex projects. The Project Team is still required to produce something physical for the customer and stakeholders at the end of each Sprint. The **Sprint Review** occurs at the end of each Sprint with the aim to present the Sprint result to the customer and management. As a result of this Sprint, the Scrum team presents a concept, prototype, or even a Voice of Customer study – "something tangible" (Cooper and Sommer 2016a).

The **Daily Scrum Meeting** is one of the Agile-Scrum tools that quickly integrated into the Agile-Stage-Gate approach. This is a short meeting, where the project team meets every day for 10–15 minutes to review the work progress. The Scrum Master gives every member of the team the opportunity to provide the status of what they achieved yesterday, what they expect to do today and to discuss any future problems they may foresee. During this meeting, the team collaborates and shares their collective knowledge in order to solve the problem of the day.

The purpose of the **Retrospect Meeting** is to improve the standard way of doing things. The team members discuss their successes and failures from the previous Sprint and try to solve the key issues that prevented them from reaching peak performance. In this meeting, each team member shares their concerns and suggestions on how to self-improve for the next Sprint.

The Agile-Stage-Gate approach adopts most of the Agile-Scrum tools. The **Product Backlog** is an agile tool that has also been adopted by Agile-Stage-Gate. The Product Backlog is equivalent to the product definition (or requirements specification) in traditional project management. Unlike standard product definition, however, the Product Backlog does not contain a detailed specification of the product but rather highlights the customers' needs and requirements. The Product Backlog is a dynamic document in which items are prioritized, and the most crucial obstacle is tackled first.

The **Sprint Planning Meeting** occurs at the beginning of each Sprint. The Project Team takes the top priority items from the Product Backlog (which is maintained by the Product Owner) and creates the Sprint Backlog, a list of the most critical items to be implemented in the current Sprint. The Product Owner decides what moves to the top of the list, while the team translates these items into clearly defined actions and estimates the time needed to accomplish each task.

Gates and **Stages** are still applied in the Agile-Stage-Gate hybrid approach. Each Gate acts as a door where the Go/Kill decision is made, which allows a

project to either move on to the next stage, or be rejected and thus discontinued. The Stages provide a high-level overview of the main phases of the project. Stages and Gates provide the senior management with the ability to micromanage the process and also obtain any necessary information about the actions being implemented and the expected deliverables for each Stage.

The use of Gates is critical in the Agile-Stage-Gate approach, but the question of whether or not separate Gates should be used for products with hardware components versus products with software components still remains. Most Agile-Stage-Gate users find that having multiple Gates for different deliverables within the same project is troublesome and not beneficial. It is more efficient to have one Gate and one Gatekeeper to control each Stage and make the Kill/Go decisions. Because of the high level of uncertainty in the early Stages, Gates in the Agile-Stage-Gate approach are more flexible and focus more on what is delivered, not on the Kill/Go decision structure.

RQ2/RQ3 - Roles and responsibilities instituted by companies using the Agile-Stage-Gate model

In 2016, Cooper and Sommer presented the results of their Agile-Stage-Gate hybrid model case study, which examined two global manufacturing companies (Cooper and Sommer 2016a). The case study highlighted how these companies did not adopt all Agile-Scrum roles but continued to use one or more of the familiar roles and traditional responsibilities (including Project Leader, Project Manager, and Team Members). For instance, the companies used the title "Project Leader" instead of "Product Owner" for the individual who was responsible for leading the project. In the case of more complex, large scale projects, the companies sometimes had a "Process Manager", whose role is similar to that of the traditional "Project Manager". Although the responsibilities associated with the roles' terms were similar to those in the Agile-Stage-Gate approach, the titles used were markedly different (Cooper and Sommer 2016a).

In the Agile-Stage-Gate model, the **Project Leader** is one of the project team members and is responsible for pushing the project forward to its ultimate goal. The Leader is responsible for managing the resources and handling the external interfaces of the project with senior management, as well as generating a clear value proposition and ensuring stakeholder commitment.

The **Product Owner** owns the Product Backlog and is responsible for communicating the project vision to the team. The aim of this role is to focus on maximizing the product value and ensure that all necessary steps are completed within the Sprint. The Product Owner is also responsible for prioritizing and managing the Product Backlog and works closely with the development team to ensure they are moving in the right direction. The Product Owner shares some of the same responsibilities as the Project Leader in traditional product development. Some companies prefer to label the role of **Project Leader** as **Product Owner** in order to avoid confusion. In contrast, the responsibility of the **Project Manager** is to verify that the project is functioning well and that all project management tools and methods are being employed.

Many Agile-Stage-Gate users implement the **Gatekeeper Role** at the leadership level, which stems from the Stage-Gate system. This role allows senior management to review the project periodically, kill weak projects, and make resource commitment decisions so that the project team can secure the funding and personnel needed to accomplish the project. The resource commitment is imperative in terms of accelerating the work and reducing the time-to-market (Cooper and Sommer 2016a). In addition, the Gatekeeper Role allows senior management to track the project's progress and performance in each Gate.

The **Project/Process Manager** and the **Project Leader** are highly valuable and essential roles in the Agile-Stage-Gate approach. The roles are best split between two different people, preferably a Product Owner or Project Leader and a Scrum Master. The **Project Manager** or **Scrum Master** can often support multiple projects at once, depending on the size and complexity of each project. When managing smaller projects, the team leader will sometimes take on each role and act as both a leader and project manager (Cooper and Sommer 2016a). Based on the research results outlined in this paper, the roles and responsibilities in the Agile-Stage-Gate approach are noticeably different from company to company and depend primarily on the size and complexity of each project. Since each company tailors this new hybrid approach to fit their specific needs, the terminology for these roles and responsibilities are inconsistently applied from company to company and project to project, leaving room for ambiguity and miscommunication.

RQ4 - What effect does the Agile-Stage-Gate model have on project team quality, including 1) communication and 2) coordination?

Team communication, coordination, and performance are essential components to measure when operating under the Agile-Stage-Gate approach. The project team is co-located and dedicated to one project with designated project rooms. The team uses visual, physical scrum boards to produce efficient developments and better communication. Scrum meetings are conducted daily within the teams at their Scrum boards and are facilitated by the Scrum Master. When operating from the Agile-Stage-Gate approach, the project team remains intact for the lifespan of the project to ensure ownership and accountability. Isolation from other parts of the organization is the main challenge that arises from having a dedicated team.

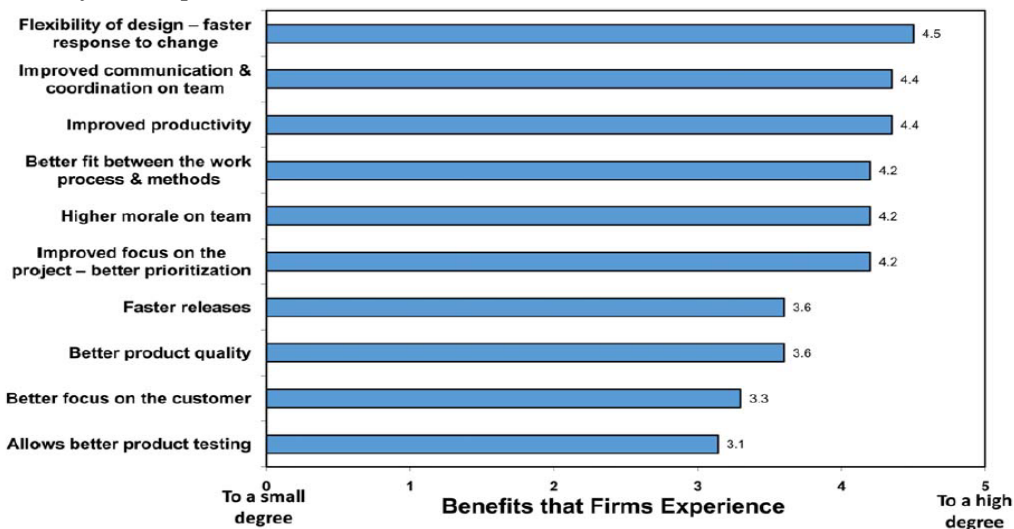
In the Agile-Stage-Gate approach, the Sprint board is still used to outline the Sprint Backlog, which lists all the activities and tasks that must be completed during the Sprint. There are many ways to utilize the Sprint board, but the most common format is to use three columns: "To-do", "Doing", and "Done". The Sprint board is a useful tool to track Sprint tasks and to monitor team activities (Cooper and Sommer 2016a).

The Danish study revealed that employing the Agile-Stage-Gate approach reduced work effort by 25% per project, reduced repeated work by nearly 20% and improved efficiency overall (Cooper and Sommer 2016b). The five organizations that were studied also observed an increase in the visibility of processes, improved

team ownership, and overall motivation. Additionally, the manufacturing firms noticed a significant improvement in the communication within the team and in the coordination across the whole organization.

In order to measure performance, the Danish researchers created their own consistent metrics across all five of these companies. These metrics, as presented in Figure 7, outlines the results of the Danish study and reveal significant improvements, including faster response time to product changes and customer requirements. The results also reveal an improvement in team communication, ownership and project productivity.

Figure 7. *Benefits from Implementing the Agile-Stage-Gate Approach (Mean Scores of 10 Respondents across 5 Firms)*

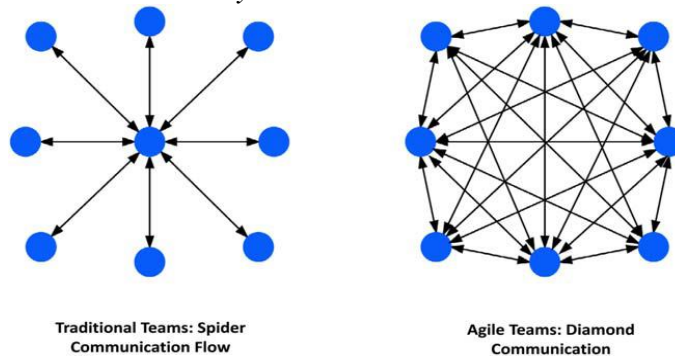


Source: Cooper and Sommer 2016.

The results from the Danish study also align with the Agile-Stage-Gate case studies that Dr. Robert Cooper conducted in the United States in 2016. The American companies Dr. Cooper studied were early adopters of the Agile-Stage-Gate hybrid approach. Each of the five organizations reported an improvement in product requirement modifications, better team communication and a reduction in time-to-market response. Although Dr. Cooper's studies are somewhat limited in scope, when his results are combined with the previous results of the Danish study, the research strongly suggests that the Agile-Scrum method can be seamlessly integrated into the Stage-Gate system and that the two methods are remarkably compatible (Cooper and Sommer 2016a).

Several manufacturing firms have adapted the Agile-Scrum approach at the operational level (Sommer et al. 2015). Applying Agile-Scrum at this level allows the project team to benefit from the broad range of communication paths provided by the Agile-Scrum model versus the limited communication styles found in traditional models, as seen in Figure 8.

Figure 8. Communication Paths Provided by the Agile-Scrum Model vs. Traditional Communication Styles



Source: Cooper and Sommer 2016b.

As seen in Figure 8, a spider communication flow is used in the traditional methods where the Project Manager remains the focal point for all communications. This structure strictly limits the amount of communication that takes place between project members. In contrast, adapting the Agile-Scrum method within the hybrid approach opens up more communication pathways between team members, which increases the sharing of knowledge and collaboration within the project team (Cooper and Sommer 2016b).

RQ5 - What is the long-term company strategy and vision when applying the Agile-Stage-Gate model?

Most Agile-Stage-Gate users keep the Stage-Gate unchanged at the management level and implement Agile-Scrum at the operational level (Cooper and Sommer 2016a, Sommer et al. 2015). This strategy allows the organization to manage its portfolio and allows the Portfolio Manager to clearly see the progress of the project and status of the product backlog (Cooper and Sommer 2016a). Using a virtual software tool that creates visual boards further enables companies to not only manage individual projects but to monitor and control the full project portfolio in real-time. In addition, these visual boards allow managers to run analytics across the portfolio of all projects in order to see the actions and types of tasks being implemented by specific people and departments. Managers are also able to monitor and control the resource capacity in order to improve project planning within the portfolio.

In traditional methods, the Portfolio Manager receives periodical reports on the project's status, which may delay the necessary intervention by weeks at a time. In contrast, the enhanced capability inherent in the Agile-Stage-Gate model allows potential problems to be immediately identified so that the required actions can take place without delay (Cooper and Sommer 2016a). Although there is still a limited amount of research that focuses on the performance results achieved when implementing the Agile-Stage-Gate approach for physical products, the available research still provides positive evidence that this new hybrid approach reduces time-to-market and increases the success rate of projects (Cooper and Sommer 2016b).

Learning how to maneuver the uncertainty involved in new product development is crucial to the ultimate success of a product. For innovative products that use new technology and are new to the market, staying attuned to the voice of the customer and performing technical assessments or market analyses does not reduce all risk when dealing with the uncertainties that exist prior to the development stage. Understanding customer needs and values on a deeper level can technically only be learned through experimentation. The sprint-iterations process in the Agile-Stage-Gate model provides an excellent environment in which to experiment and test the prototype. The Project Team can begin by first understanding the product requirements and then envision a technical solution during the Development and Testing stages of the project. The Agile-Stage-Gate approach also allows the Project Team and the customer to learn more about the product during the Development and Testing stages, especially for more innovative products.

Ever-changing product requirements pose a significant challenge when it comes to new product development. Traditional gating models often struggle to respond and adapt to these changing requirements, especially by the time they enter the late stages. In contrast, the Agile-Stage-Gate approach rapidly builds a prototype via the Sprints, which allows the customer and the Project Team to implement any necessary modifications in the product design during the development stage at a much lower cost.

Methodology

Research Method

Since the Agile-Stage-Gate model is a relatively new approach that has only recently been adopted by the manufacturing industry, the structure, roles, and responsibilities have not been clearly defined or standardized. Instead, each firm adopts and modifies its own version of this hybrid approach. In order to examine the similarities and differences among companies who have adopted this model in more depth, a survey was created and conducted in order to investigate the recurring patterns that emerge when the Agile-Stage-Gate approach is implemented.

Survey Design

The survey questions were developed by first reviewing the available literature on the Stage-Gate method, Agile-Scrum, and the Agile-Stage-Gate approach, along with a round table discussion with Subject Matter Experts (SME). to establish result expectations. As a result, the survey covers seven main categories of research questions. This specific survey approach was selected because obtaining data from participants who have varied experience with multiple projects and products helped to define the structure of the Agile-Stage-Gate model, as well as the roles and responsibilities involved. The survey has 71 questions divided into seven groups:

1. Participant experience and knowledge
2. Structure and features in the Agile-Stage-Gate approach
3. Project team roles in the Agile-Stage-Gate approach
4. Responsibilities in the Agile-Stage-Gate approach
5. Communication and teamwork performance in the Agile-Stage-Gate approach
6. Company strategy for adapting the Agile-Stage-Gate approach
7. Agile-Stage-Gate approach performance rate

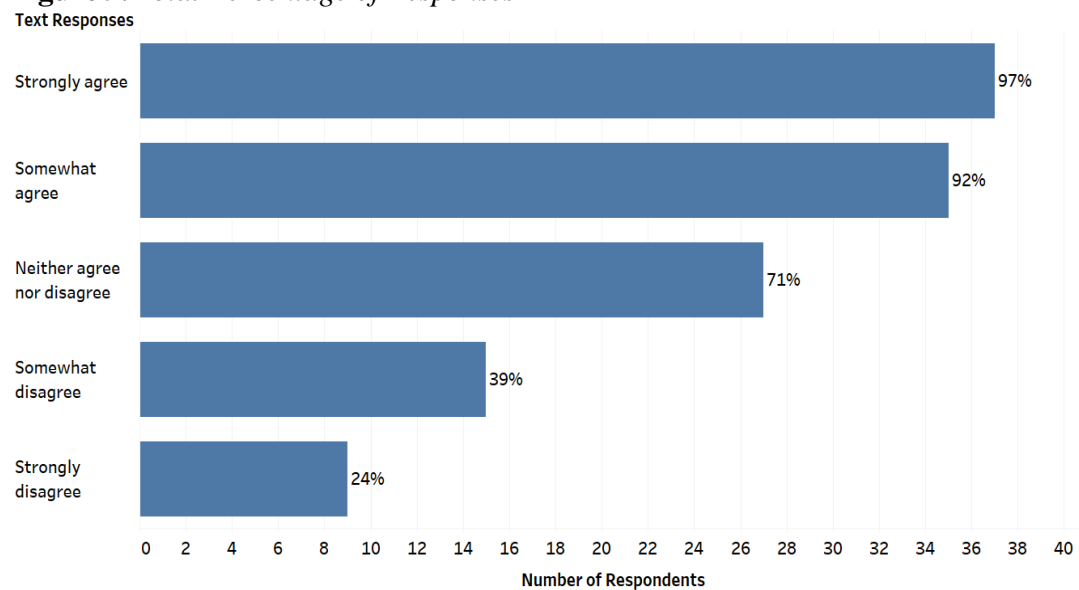
Respondents were asked to answer each question by selecting an agree/disagree statement that ranged from 1 to 5 (1-Strongly disagree, 2-Disagree, 3-Neutral, 4-Agree, 5-Strongly agree). For each research question, multiple answers were presented based on different **Product and Project Types** to understand the similarities and differences that exist within the Agile-Stage-Gate approach.

Data Collection and Visualization

The survey was launched online using the Qualtrics tool and distributed on multiple social media platforms and on several Project Management websites and was redistributed every three days for one month. The target population was experts who already had experience with the Agile-Stage-Gate approach in the manufacturing industry. Following a one month posting, 144 responses were collected with incomplete responses not considered for the research process. Using Tableau Desktop Software multiple factors were applied to create specific charts, such as product and project type. The application of these factors and variables helped to clearly highlight the elements that affect the implementation of the Agile-Stage-Gate approach within different products and projects.

Respondents

A final 52 qualified respondents became the final pool from which the research results were based upon. Overall, 97% of the respondents were in strong agreement with all the survey questions as shown in Figure 9.

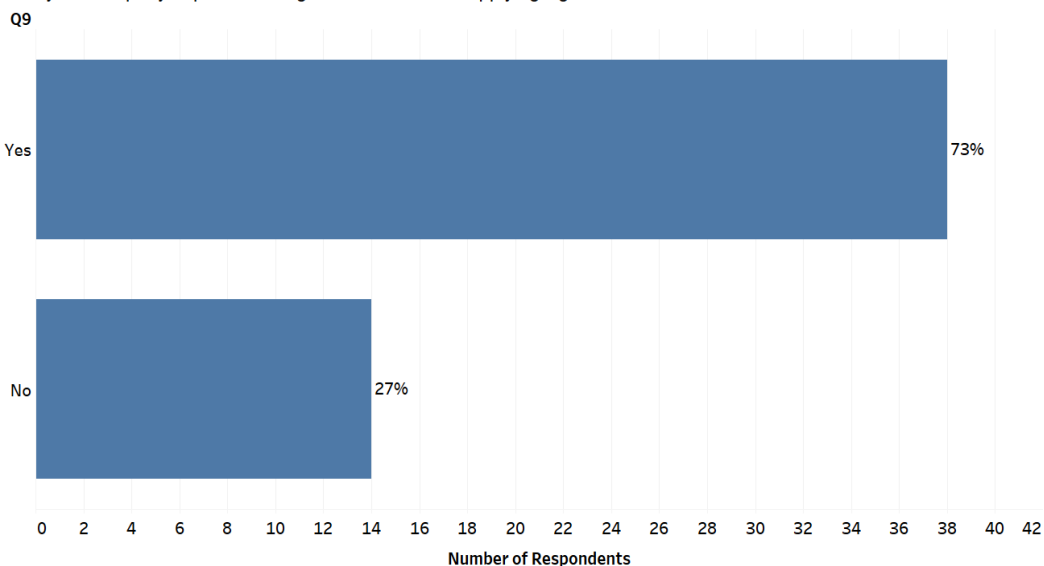
Figure 9. Total Percentage of Responses

The demographics reflecting the respondents' experience, educational background, participant's organization, project types, geographic location, and those that are using a form of Agile–Stage Gate have been removed to conserve publishing print space (Figures 10–15 were removed).

Results and Analysis

Figure 16. Percentage of Companies that Implemented the Stage-Gate Model First

Q9- Did your company implement Stage-Gate first before applying Agile?



To analyze the results of the six groups of survey questions, specific filters were applied firstly to respondents who selected "Strongly Agree" to the survey

questions (see Figure 9), followed by specific factors pertaining the differences between the structures, roles, and responsibilities and additionally to each group based on the product and project type that companies manage. A third filter was applied to the type of project such as New Product Development (NPD), Research & Development (R&D), and Services. Figure 16 indicates the Percentage of companies that implemented the Stage-Gate model first, prior to the application of Agile. All of the figures referenced below are provided in the Appendix.

Common Structures and Features in the Agile-Stage-Gate Approach

The results (Figure 17) show that the integration of the Agile-Scrum model is not limited to a specific stage. Instead, manufacturing firms apply this model throughout different stages of the Stage-Gate model. This finding reveals that the integrated approach can be implemented throughout every stage. Dr. Robert Cooper obtained the same results from his Agile-Stage-Gate case studies, which revealed there is not only a possibility of using the Agile-Stage-Gate model during Development and Testing but during the earlier stages as well (Vedsmand et al. 2016).

Common Structures and Features of the Agile-Stage-Gate based on Product Type

The results related to this section were filtered based on the product and project types (**Software**, **Hardware** and **Combination**) in order to learn more about the Agile-Stage-Gate structure. The survey's findings revealed that the structure of the Agile-Stage-Gate approach varies slightly depending on the participant's opinion. For example, in the case of **software products** (Figure 18) respondents strongly agreed that companies integrate all the features of Agile-Scrum into the Stage-Gate model. This means that the Agile-Stage-Gate approach combines all Agile-Scrum and Stage-Gate structures and features under one model.

In contrast, the results that were in agreement for **hardware** and **combination** products have a lower percentage overall than for software products (Figures 19 and 20). It would appear that companies are still determining how to best combine both models when working with hardware and combination products. Regarding the implementation of the Agile-Scrum into different stages, the results based on the **product type** show that the implementation of the Agile-Scrum model is not limited to the Development and Testing stages and can effectively be applied to all stages.

Common Structures and Features based on Project Type

Results filtered by project type, (**NPD**, **R&D**, and **Services**) all the established structures and features are still applied in the hybrid model, but with different levels of agreement (Figures 21 and 22). Participants 33% of the time indicated more familiarity integrating the Agile-Stage-Gate model when managing **NPD projects**.

Regarding **service** projects, none of the respondents (Figure 23) strongly agreed that the Agile-Scrum model is implemented throughout all the stages of the project. Overall, the results in this section indicate that the early adopters are still

attempting to find the best combination of both the Stage-Gate and Agile-Scrum models. This result also highlights the room for improvement when it comes to companies adjusting and modifying the hybrid approach during implementation.

Project Team Composition and Roles within the Agile-Stage-Gate Approach

Figure 24 showed that the Project Team consists of a Product Owner, Scrum Master and the Development team according to 47% of respondents. 50% of participants reported that there is also a steering committee and that the project team is co-located and dedicated to one project.

The project team's roles, indicated in Figure 25 show that the titles of Product Manager, Product Owner, Project Manager, Scrum Master and Business Analyst are all recurring roles within the Agile-Stage-Gate approach.

Project Team Roles in the Agile-Stage-Gate Approach based on Product Type

100% of the respondents strongly agreed (Figure 26) that there is always a Gatekeeper, Product Manager, Product Owner, Project Manager and a Scrum Master during **software** development and 50% of the strongly agreed on the team roles associated with **Hardware products**, (Figure 27).

For products that have a **combination** of software and hardware components, 71% strongly agreed that there is always a Product Manager role (Figure 28) and 64% introduced the Business Analyst as a hybrid role, who takes on the role of the Project Manager and/or the Product Owner.

Based on the results of the survey, companies appear to adjust the project team roles based on different product types. Therefore, an extensive analysis of the survey's results was conducted based solely on the product type being considered. By comparing the results through the filter of product type, it was found that all the roles have been integrated into the Agile-Stage-Gate approach for software and combination products. The only exception is the Business Analysis role, which does not get a high level of agreement as seen in Figures 26 and 28. Although the participants strongly agreed that all these roles existed in the case of software products, this could potentially create future conflict if the responsibilities are not identified clearly, leading to impeded efficiency and productivity.

Project Team Roles in the Agile-Stage-Gate Approach based on Project Type

In **New Product Development Projects** (Figure 29), 71% of respondents strongly agreed that there are always Product Owner and Scrum Master roles, while 57% strongly agreed that there are always Project Manager and Business Analyst roles. For **R&D Projects**, only 17% of respondents strongly agreed that there are always Gatekeeper, Product Owner, Scrum Master and Business Analyst roles in the Agile-Stage-Gate approach (Figure 30). In contrast, 0% of the respondents strongly agreed that these roles exist for projects that provide **services to customers** (Figure 31).

It was found that the Agile-Stage-Gate approach integrates the team roles based on the project type normally associated with NPD projects, while in contrast, roles associated with R&D projects received a very low percentage of agreement

and there was no agreement at all in the case of service projects. Thus it would appear that the normal roles do not transfer over into services projects and R&D projects.

Adjusted Project Team Roles after Adopting the Agile-Stage-Gate Approach (based on Product Type)

Findings indicate that implementing the Agile-Stage-Gate hybrid model requires organizations to modify aspects of roles and responsibilities to ensure that individuals achieve their tasks and maximize all the benefits available within this combination of models. Even more important, organizations must remove any conflict between roles and ensure there is no interference between the responsibilities of the project team. Findings indicate (Figure 32) that some of the roles have been adjusted when companies adopted the Agile-Stage-Gate approach. For example, 100% of participants strongly agree that the Project Manager takes on most of the Scrum Master role for Software product development while in contrast (Figure 33) shows that only 25% strongly agree that the Project Manager takes on most of the Product Owner role for Hardware products.

Adjustments are made to the existing roles in the team roles when adopting the new approach developing combination products. For example (Figure 34) 43% strongly agreed that the Product Manager takes on most of the Product Owner role, 29% strongly agreed that the Project Manager takes on most of the Product Owner role and 36% agreed the Project Manager takes on most of the Scrum Master role, indicating that the roles in the hybrid approach can be slotted into existing roles.

Adjusted Project Team Roles after Adopting the Agile-Stage-Gate Approach (based on Project Type)

For **NPD** projects, 57% strongly agreed (Figure 35) that the Product Manager takes on most of the Product Owner role. 50% strongly agreed that the Project Manager takes on most of the Product Owner role. In the case of **R&D** projects, Figure 36 shows that 17% strongly agreed that the Product Manager both takes on most of the Product Owner role, and that the Project Manager takes on most of the Scrum Master role. For projects providing **Services**, again 0% strongly agreed on the adjusted roles (Figure 37).

Results of this section show that most of the roles can be easily adjusted for NPD, which differ from the roles applied to R&D and Services projects, indicating that defining roles is often dependent on the type of project.

Project Team Responsibilities in the Agile-Stage-Gate Approach

Respondents 63% of the time (Figure 38) strongly agreed that the responsibilities of the **Project Manager** are to manage the project in terms of scope, cost and time using a project plan with defined deliverables, detailed budgets and a milestone plan and 53% strongly agreed that the **Product Manager** is responsible for providing a clear, prioritized Product Backlog, keeping track of feedback and incorporating it as needed into the Product Backlog. Meanwhile,

55% strongly agreed that the **Scrum Master** is responsible for facilitating the Scrum process and communication, as well as tracking team performance.

Project Team Responsibilities in the Agile-Stage-Gate Approach (based on Product Type)

Participants strongly agreed that all responsibilities of the project team were identifiable in the Agile-Stage Gate approach and understanding the similarities and differences of these responsibilities was important. 100% of respondents (Figure 39) strongly agreed that the responsibilities of the **Project Manager** include managing the project in terms of scope, cost, and time using a project plan with defined deliverables, detailed budgets and milestones and that 100% strongly agreed that **the Product Owner** is responsible for providing a clear, prioritized Product Backlog, keeping track of feedback and incorporating the feedback as needed into the Product Backlog.

The distribution of responsibilities for **Hardware** products produced different results as only 25% (Figure 40) **strongly agreed** that the responsibilities of the **Project Manager** include managing the project in terms of scope, cost and time using a project plan with defined deliverables, detailed budgets, and milestones. However, 100% strongly agreed that **the Scrum Master** is responsible for facilitating the Scrum process and communication, as well as tracking team performance.

For **combination** products (Figure 41) 57% strongly agreed that the responsibilities of the **Project Manager** include managing the project in terms of scope, cost and time using a project plan and 50% of participants strongly agreed that **the Product Owner** is responsible for providing a clear, prioritized Product Backlog, keeping track of feedback. There were 43% that strongly agreed that **the Scrum Master** is responsible for facilitating the Scrum process and communication, as well as tracking team performance.

The hardware product questions had less overall agreement regarding these responsibilities. However, the participants were in 100% strong agreement on most responsibilities applied to software products. This leads to the conclusion that project teams working on software products specifically have more defined and clear responsibilities when operating within the Agile-Stage-Gate approach.

Project Team Responsibilities in the Agile-Stage-Gate Approach (based on Project Type)

For **NPD projects**, 64% of respondents strongly agreed that the responsibilities of the **Project Manager** are to manage the project in terms of scope, cost and time using a project plan with defined deliverables, detailed budgets and milestones (Figure 42), while 57% strongly agreed that **the Product Manager** is responsible for providing a clear, prioritized Product Backlog, keeping track of feedback, and incorporating it as needed into the Product Backlog and 50% strongly agreed that **the Product Owner** is responsible for the same tasks as the Product Manager.

For **R&D projects**, (Figure 43) 33% of respondents strongly agreed that the responsibilities of the **Project Manager** include managing the project in terms of scope, cost and time with defined deliverables, detailed budgets and scheduled

milestones, while 50% strongly agreed that **the Product Owner** is responsible for the same tasks as the Product Manager, and 50% strongly agreed that **the Scrum Master** is responsible for facilitating the Scrum process and communication, as well as tracking team performance.

When analyzing designated responsibilities for **Service projects**, 100% of respondents strongly agreed that **the Scrum Master** is responsible for facilitating the Scrum process and communication, as well as tracking team performance (Figure 44). The results relating to responsibilities in regards to NPD and R&D projects are robust and it is clear that the responsibilities are well-defined and decisively assigned.

Communication and Coordination in the Agile-Stage-Gate Approach

Regarding project team communication, shared values and team coordination when implementing the Agile-Stage-Gate approach, 55% of respondents (Figure 45) strongly agreed that the approach allows the team to **share their values and lessons** with the rest of the organization and 61% were in strong agreement that the approach **creates effective communication** among project team members.

Project Team Communication and Coordination (based on Product Type)

Overall, there was a substantial level of agreement in regards to communication and coordination. In the case of **software products**, 100% of respondents (Figure 46) strongly agreed that the Agile-Stage-Gate approach encourages the team to share their values and lessons with the rest of the organization and 100% of participants were in strong agreement that the approach creates and improves more effective communication and coordination and improves team ownership and motivation. In contrast, only 25% strongly agreed that the approach allows the team to better share their values and lessons with the rest of the organization during **hardware product development** (Figure 47).

When developing a **product that has a combination of components** 57% (Figure 48) strongly agreed that the Agile-Stage-Gate approach encourages the team to share their values and lessons with the rest of the organization, while 64% were in strong agreement that the approach creates more effective communication.

Findings indicate that adopting the Agile-Stage-Gate approach has different results based on how the model is applied, whether in software, hardware, or combination products. It would appear that the approach has a positive impact on communication, coordination and ownership for software products and improves each of these areas respectively. In contrast, the approach has less impact when it comes to improving communication, coordination and ownership for combination products.

Project Team Communication and Coordination (based on Project Type)

In the case of **NPD**, 50% of respondents (Figure 49) strongly agreed that the Agile-Stage-Gate approach encourages the team to share their values and lessons with the rest of the organization, while only 57% were in strong agreement that the approach creates effective communication within the project team. For **R&D**

projects, only 17% of respondents (Figure 50) strongly agreed that the Agile-Stage-Gate approach encourages the team to share their values and lessons with the rest of the organization and 33% of participants were in strong agreement that the approach creates effective communication within the project team, improves overall communication and coordination and enhances team ownership and motivation.

For **services projects**, 100% of respondents strongly agreed that the Agile-Stage-Gate approach encourages the team to share their values and lessons with the rest of the organization (Figure 51). The project type filter revealed that NPD projects have the best impact on team communication and coordination when integrated with the approach. We can thus conclude that companies are more familiar with the approach when managing NPD Projects.

Agile-Stage-Gate Tools

Respondents **61%** (Figure 52) of the time strongly agreed that if the cross-functional teams cannot be present in one place, a **virtual meeting** tool can be used in lieu of daily in-person stand-ups and **45%** of participants strongly agreed that the project team has a **daily scrum meeting**, **53%** strongly agreed that the **Scrum Task Board** is still used and **42%** strongly agreed that the **Sprint Review** meeting is still implemented so that the team can demonstrate the completed features and receive stakeholder feedback.

Agile-Stage-Gate Tools (based on Product Type)

When developing **software products**, 100% of respondents (Figure 53) strongly agreed that a virtual meeting tool can be used in place of daily in-person stand-ups if the cross-functional teams cannot be present in one place, while just 50% strongly agreed that the project team has a daily scrum meeting and that the Sprint Review meeting is still applied. For **hardware products**, 50% of respondents (Figure 54) strongly agreed that a virtual meeting tool can be used instead of holding daily in-person stand-ups if the cross-functional teams are not present and 50% strongly agreed that the Scrum Task Board is still applied in the Agile-Stage-Gate approach. For **combination** products, 50% of respondents (Figure 55) strongly agreed that if the cross-functional teams cannot be present in one place, a virtual meeting tool can be used instead.

Most of the Agile-Scrum tools, such as the Sprint Review meeting and Daily Scrum Meeting, are still applied in the Agile-Stage-Gate approach. However, some modifications do take place, like the possibility of holding a virtual meeting instead of an in-person meeting. It seems that these tools are more applicable when developing **software** and **combination** products with respondents indicating a very strong agreement that the project team is not isolated from the rest of the organization during software product development. In contrast, the results show that the project team is somewhat more isolated from the rest of the organization for other types of product development. Isolation may therefore decrease if companies dedicate more focus and attention to the project team when using the approach for hardware and combination products.

Agile-Stage-Gate Tools (based on Project Type)

In the case of **NPD** projects, 71% of respondents (Figure 56) strongly agreed that a virtual meeting tool can be used instead of holding daily in-person stand-ups and 64% of participants strongly agreed that the project team has a daily scrum meeting.

For **R&D projects**, 17% (Figure 57) strongly agreed that a virtual meeting tool can be used in lieu of daily in-person stand-ups if the cross-functional teams are not present in one place and 50% strongly agreed that the Scrum Task Board is still used in the Agile-Stage-Gate approach. When analyzing **services projects**, 0% (Figure 58) strongly agreed that a virtual meeting tool can be used instead of daily in-person stand-ups as well as 0% strongly agreed that the project team has a daily scrum meeting. When managing different projects, it is essential to identify what kind of communication tools are most effective within the Agile-Stage-Gate approach. The survey results revealed that Agile-Stage-Gate tools (such as the virtual meeting, daily scrum meeting, Scrum Task Board, and Sprint Review meeting) were used extensively for new product development projects.

Organizational Strategy when Adapting the Agile-Stage-Gate Approach

The fifth research question (RQ5) aimed to identify factors that encourage companies to adopt this relatively new Agile-Stage-Gate approach and how this adoption integrates into their overall company strategy. **53%** (Figure 59) strongly agreed that the approach allows the company to better deal with uncertain situations and effectively manage complex projects and **58%** strongly agreed that this approach allows senior management to be more involved with all stakeholders.

Organizational Strategy in the Agile-Stage-Gate Approach (based on Product Type)

In the case of **software products**, 100% (Figure 60) strongly agreed that the Agile-Stage-Gate approach allows the company to better deal with uncertain situations and effectively manage complex projects, 50% strongly agreed that this approach allows senior management to be more involved with all stakeholders and 100% strongly agreed that this approach more effectively integrates the voice and needs of the customer throughout every step of the process.

In the case of **hardware products**, only 25% (Figure 61) strongly agreed with most of the statements in this section while **75%** strongly agreed that Agile-Stage-Gate is an efficient approach that allows companies to more quickly respond to the increasing demand for new and innovative products. In contrast, **57%** (Figure 62) strongly agreed that the approach allows the company to deal with uncertain situations and effectively manage complex projects for products with a **combination** component and **43%** strongly agreed that this model allows senior management to be more involved with all stakeholders.

It can be concluded that the Agile-Stage-Gate approach is markedly beneficial in terms of allowing senior management to be more involved with all stakeholders and helping companies to retain control over projects on both the strategic and

executive levels. The hybrid model also seems to enable companies to respond quickly to market changes and align the projects with the company strategy.

Most participants strongly agreed that companies can achieve excellent results on very critical goals using the hybrid approach, such as handling uncertain situations and managing complex projects effectively. In the case of software and combination products, participants also strongly agreed that this new approach enables companies to respond quickly to market changes and gives them the ability to align projects with the company strategy. It can therefore be concluded that companies managing software products have an excellent chance to achieve results in line with their long-term strategy by adopting the Agile-Stage-Gate approach.

Organizational Strategy in the Agile-Stage-Gate Approach (based on Project Type)

In the case of **NPD**, **50%** of respondents (Figure 63) strongly agreed that the Agile-Stage-Gate approach allows the company to better handle uncertain situations, effectively manage complex projects and allows the senior management group to be more involved with all stakeholders. **57%** strongly agreed it helps companies overcome the challenges of developing smart and connected products at a lower price point and **71%** strongly agreed that this approach provides the company with the ability to align the projects with the company's strategy.

For **R&D projects** findings reveal that the level of agreement on each question related to organizational strategy is less extreme and most responses were at or under 50% (Figure 64) when compared to the results of the NPD section. For example, 50% of participants strongly agreed that the Agile-Stage-Gate approach allows senior management to be more involved with all stakeholders.

When it comes to **Services projects**, it was strongly agreed (Figure 65) that the new approach is more efficient and allows companies to respond more quickly to the increasing demand for new and innovative products. Based on the project type analysis, the Agile-Stage-Gate approach has promising results when it comes to improving the company's strategic goals with 71% of the participants citing the goals of aligning projects with the company's strategy during new product development projects.

Agile-Stage-Gate Performance Rate

To measure the overall achievement when implementing the Agile-Stage-Gate approach, criteria such as productivity, prioritization and reduced time-to-market were used to measure the effectiveness of this approach based on participant's experience. **63%** of respondents (Figure 66) strongly agreed that the approach enables companies to reduce time-to-market and improve the prioritization process and **71%** strongly agreed the approach improves product quality and productivity, with **58%** agreeing that profitability increases.

Agile-Stage-Gate Performance Rate (based on Product Type)

In the case of **Software products**, **100%** (Figure 67) strongly agreed that the Agile-Stage-Gate approach enables companies to reduce time-to-market, improve

the prioritization process and productivity as seen in. In addition, **50%** strongly agreed that product quality improves and profitability increases. For the **hardware products**, **50%** of the respondents (Figure 68) strongly agreed that the approach enables companies to reduce time-to-market and **50%** strongly agreed the approach improves product quality and overall productivity. In the case of **combination products**, **50%** (Figure 69) strongly agreed that the Agile-Stage-Gate approach enables companies to reduce time-to-market, while **71%** agreed the model improves product quality and productivity.

The survey results reveal that the Agile-Stage-Gate approach has beneficial results when it comes to improving the prioritization process, product quality and overall productivity. However, these results are more substantial when the hybrid model is applied to **software and combination** product development, rather than hardware products when comparing Figures 67 and 69 to Figure 68. It is obvious from the survey findings that the approach has a positive influence on the IT/Software industry and may be a result of this industry implementing the hybrid approach first (before combination and hardware products) and therefore has had more time to test the effectiveness of the hybrid model. These promising results will likely encourage companies to apply the hybrid approach on the hardware products in the future (Kempeneers 2019).

Agile-Stage-Gate Performance Rate (based on Project Type)

In the case of **NPD**, **64%** of participants (Figure 70) strongly agreed that the Agile-Stage-Gate approach enables companies to reduce time-to-market and **86%** agreed it improves product quality, while **71%** agreed the model improves productivity and **79%** agreed the approach increases profitability.

In the case of **R&D projects**, **67%** of respondents (Figure 71) strongly agreed that the Agile-Stage-Gate approach enables companies to reduce time-to-market, improve product quality and productivity while **50%** of participants agreed the model improves the prioritization process and increases profitability. In stark contrast, 0% of participants (Figure 72) strongly agreed on the items listed when evaluating **service projects**.

After examining the results of the Agile-Stage-Gate, it is clear that the approach has a significant impact on improving product quality, productivity, and increasing profitability when firms adopt the approach to manage **NPD** and **R&D projects** as seen in Figures 70 and 71. In contrast, the new approach has a lower percentage when it comes to services projects.

Conclusions

An overview of the standard structure, roles, and responsibilities in the Agile-Stage-Gate approach in which most participants strongly agreed, patterns emerged from the study results and that those consistent patterns improve productivity and efficiency within the team. Table 1 presents all the structures, roles, and responsibilities of the Agile-Stage-Gate approach that emerge for each product and project type and also provides the total percentage for each category that the

participants strongly agreed on. The percentages greater than 50% were highlighted to identify the most common features when implementing the Agile-Stage-Gate approach. The purpose of this table is to identify the differences and similarities of the Agile-Stage-Gate approach when it is implemented to manage different product and project types. By studying these results, manufacturing firms can learn how this approach is performing in each category, what problems it best solves and what areas of the hybrid approach still need to be improved.

Table 1. Total Percentage of the Main Survey's Areas

Task group	Product type - % Strongly agree			Project type % Strongly agree		
	Software	Hardware	Combination	New Product Development	R&D	Services
Q7- For what type of projects does your company use the Agile-Stage-Gate approach?				70%	25%	5%
Q8- For what type of products does your company use the Agile-Stage-Gate approach?	10%	20%	70%			
B. Common Structure and Features of the Agile-Stage-Gate Model	83%	25%	42%	48%	31%	0%
C. Project team roles within the Agile-Stage-Gate model	60%	17%	47%	56%	19%	7%
D. Responsibilities in the Agile-Stage-Gate model	64%	43%	49%	56%	40%	14%
E. Communication and teamwork performance in the Agile-Stage-Gate model	75%	22%	44%	51%	25%	0%
F. Organization strategy of adapting Agile-Stage-Gate model and changes	77%	20%	44%	50%	29%	18%
G. Agile-Stage-Gate rate	80%	40%	61%	70%	60%	0%
Q67-The Agile-Stage-Gate approach improves product quality.	50%	50%	71%	86%	67%	0%
Q68-The Agile-Stage-Gate approach improves productivity.	100%	50%	71%	71%	67%	0%
Q69-The Agile-Stage-Gate approach improves the prioritization process.	100%	25%	57%	50%	50%	0%
Q70-The Agile-Stage-Gate approach increases profitability.	50%	25%	57%	79%	50%	0%
Q71-The Agile-Stage-Gate approach enables companies to reduce time-to-market.	100%	50%	50%	64%	67%	0%

The result of this research provides strong evidence that the hybrid approach is a promising model when it comes to managing combination products. These findings support most of the research outcomes that were outlined in the literature review. The study also reveals that the hybrid approach can improve the management of Product Development projects as well. This is a very promising result for manufacturing firms that are willing to adopt this hybrid approach for combination products and Product Development projects.

One of the most important findings that has emerged from this study is that highest benefit that comes from integrating of the Agile-Scrum model is not limited to a specific stage, from initiation to the final stage. Instead, manufacturing firms can apply this model throughout all different stages of the Stage-Gate model.

In addition, the study shows that most of the Agile-Scrum features and Stage-Gate processes are not only effectively applied when the Agile and Stage-Gate models are combined, but also improve overall performance. Although some companies prefer to keep some of the traditional roles like Project Manager when they adopt the new approach, the study reveals that the roles in the hybrid approach can be slotted into existing roles as needed and that companies do not need to hire new employees for these positions.

My initial assumption nine months ago before diving deeply into this research was that the hybrid approach would have the greatest impact when managing products that have a combination component (software and hardware). However, the study has revealed that the Agile-Stage-Gate approach also greatly improves the efficiency and productivity of software products as well, even though the benefits of applying this approach are clear based on the survey results, surprisingly only 10% of manufacturing companies use the hybrid approach to manage software products. Perhaps in the future, there will be a higher percentage of companies that apply the hybrid approach as they will see the direct benefits to their team communication and market response time.

The hybrid approach has also been proven to positively impact many aspects of the management process, such as increasing productivity and reducing time-to-market (specifically in the case of software products). Companies currently use this approach most often for combination products and new product development projects, according to 70% of participants, as seen in Table 1. There is also a positive impact on product quality, productivity and profitability when dealing with combination products and managing new product development projects when operating within this hybrid model. Overall, the study's results indicate that the early adopters are still attempting to find the best combination of both the Stage-Gate and Agile-Scrum models. This result also highlights how much room there is for improvement and clarification when it comes to companies adjusting and modifying the hybrid approach during implementation. The maturity of the hybrid model has not yet been reached; therefore its full potential is still unknown. It is clear from the results of this research that the Agile-Stage-Gate approach does not work for every kind of products and projects. More detailed studies should be conducted to examine the application of the new approach on each type of product and project that is mentioned in this study.

The focus of this study was on the participants who strongly agree on the survey questions to best identify patterns that emerge. However, there were still a significant number of respondents selected "somewhat agree" and these answers should be considered in future studies as well. In the future, more studies should be conducted to investigate why the hybrid approach does not work for projects that provide service to customers and what should be adjusted in this hybrid approach in order for it to be the most effective option for companies to manage services projects.

The Agile-Stage-Gate approach was initially created to find a better solution for complex combination products. This study confirms that the hybrid approach is in fact the best option for combination products, but that there is also much improvement to be gained when applied to software products as well. In

conclusion, defining the consistent structure, roles, and responsibilities of this new approach is what led to these findings, and the results provide a roadmap for future companies that want improved productivity, efficiency and communication within manufacturing production.

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Appendix

Figures 10-15 were not used.

Figure 17. *Agile-Stage-Gate Structure within Companies that have Implemented Stage-Gate First*

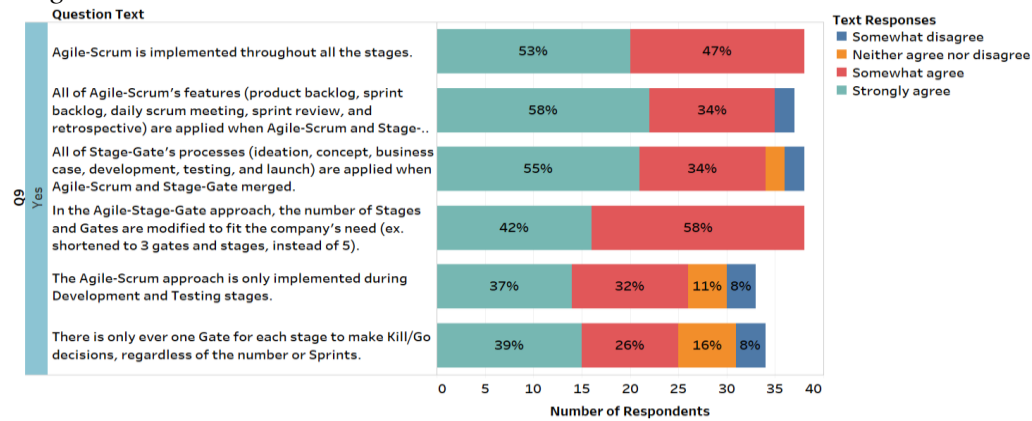


Figure 18. *Participants Describe the Agile-Stage-Gate Structure for a Software Product*

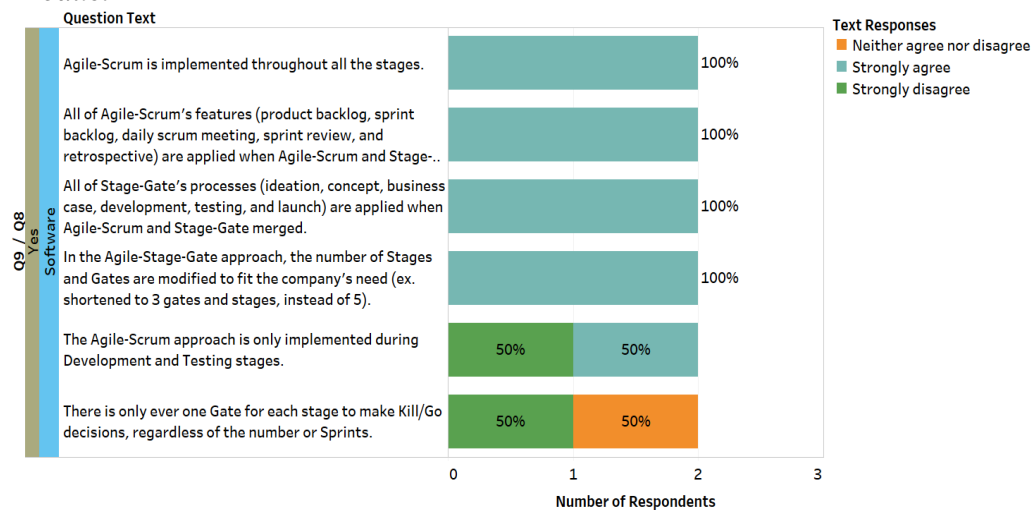


Figure 19. *Agile-Stage-Gate Structure for Hardware Products*

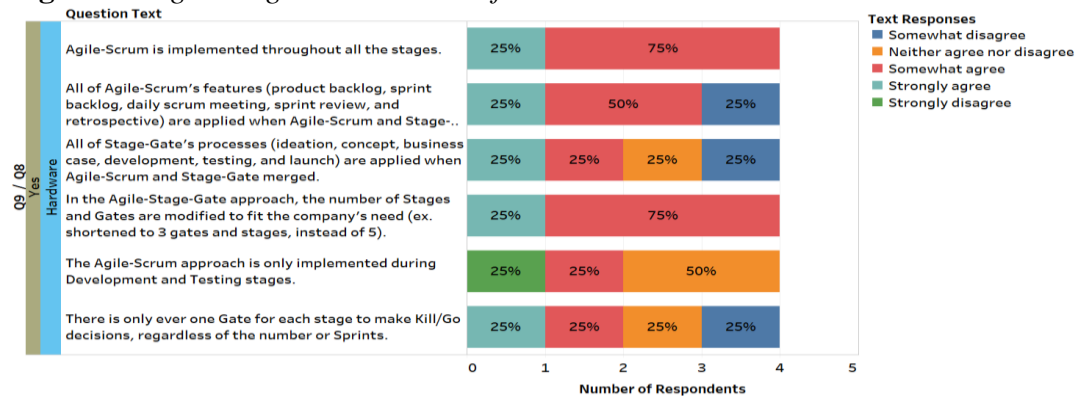


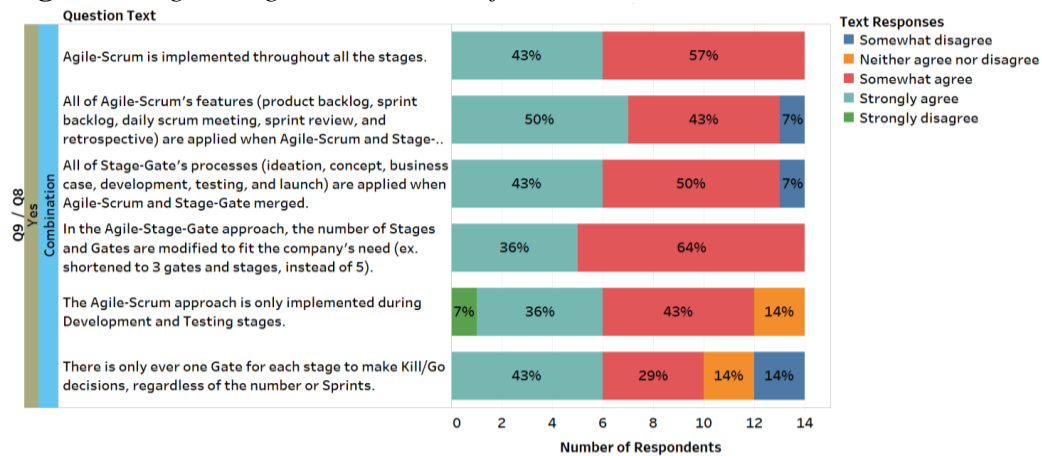
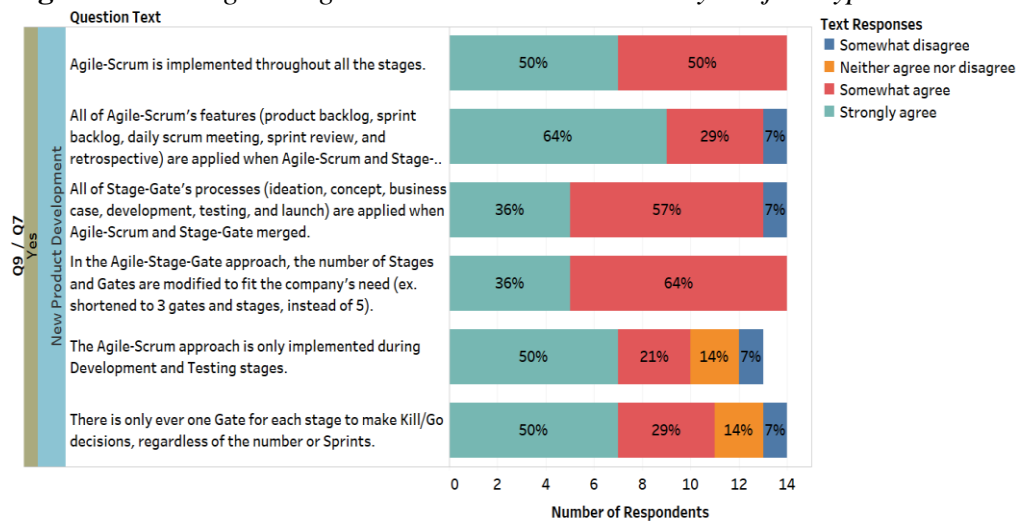
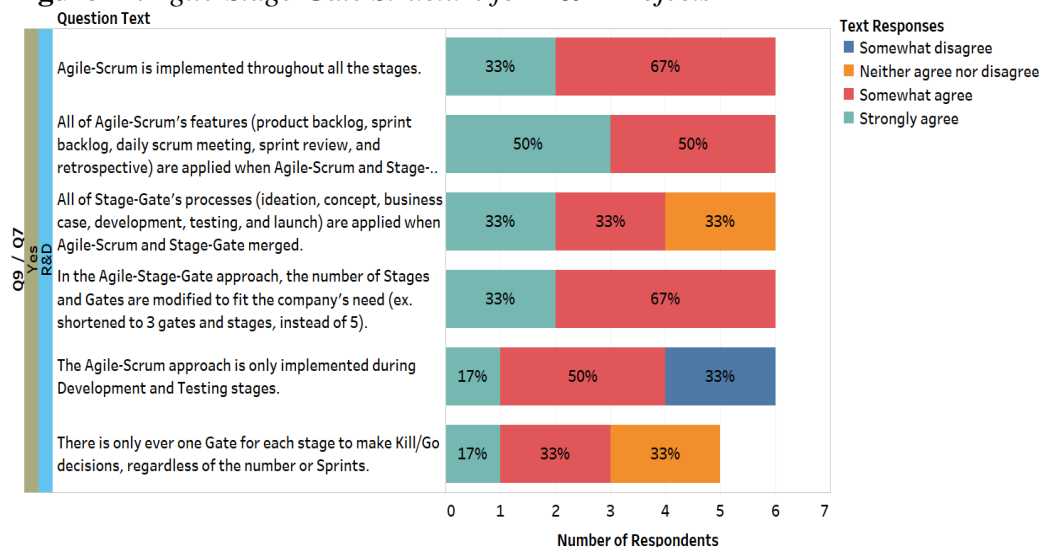
Figure 20. Agile-Stage-Gate Structure for Combination Products**Figure 21.** The Agile-Stage-Gate Structure is Filtered by Project Type**Figure 22.** Agile-Stage-Gate Structure for R&D Projects

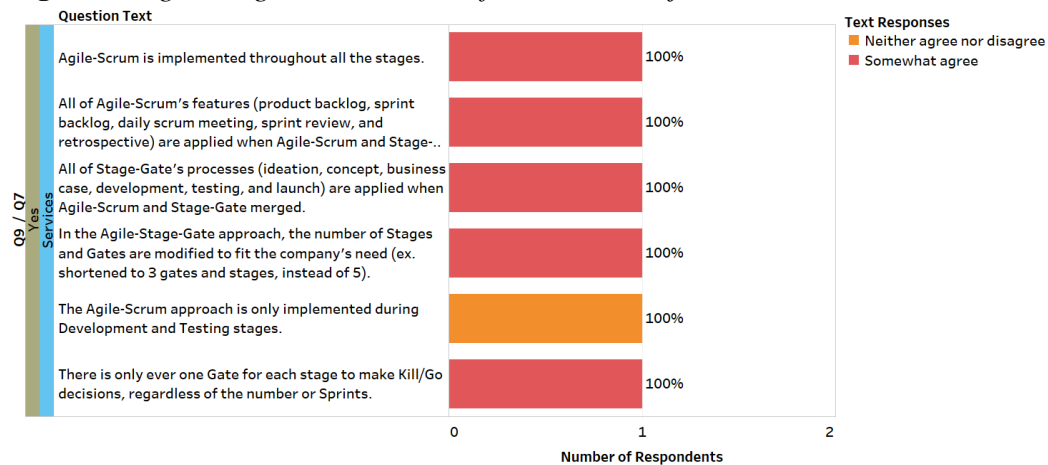
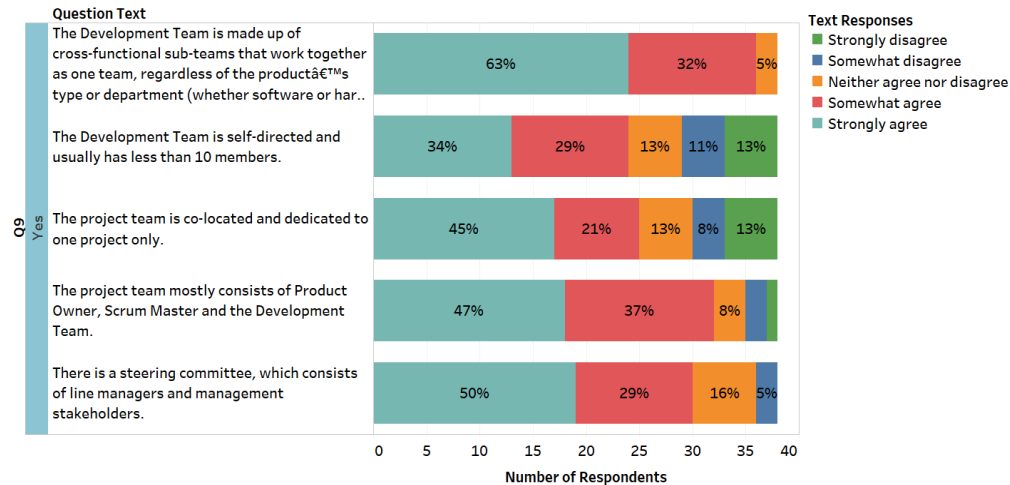
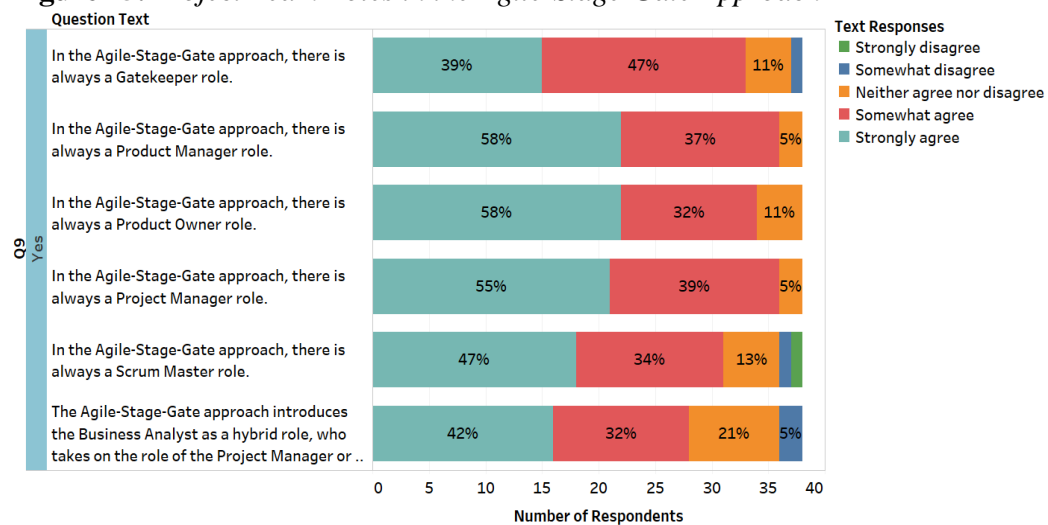
Figure 23. Agile-Stage-Gate Structure for Service Projects**Figure 24. Project Team Composition and Characteristics in the Agile-Stage-Gate Model****Figure 25. Project Team Roles in the Agile-Stage-Gate Approach**

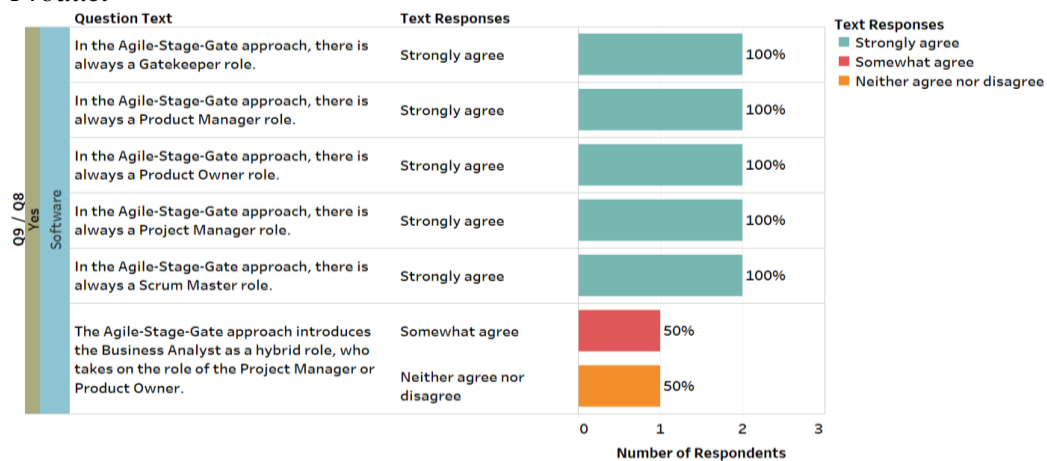
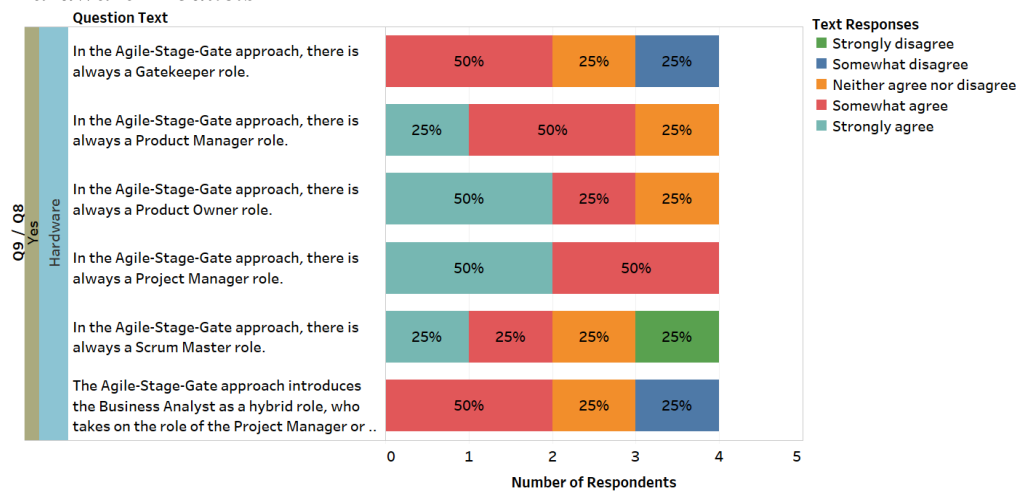
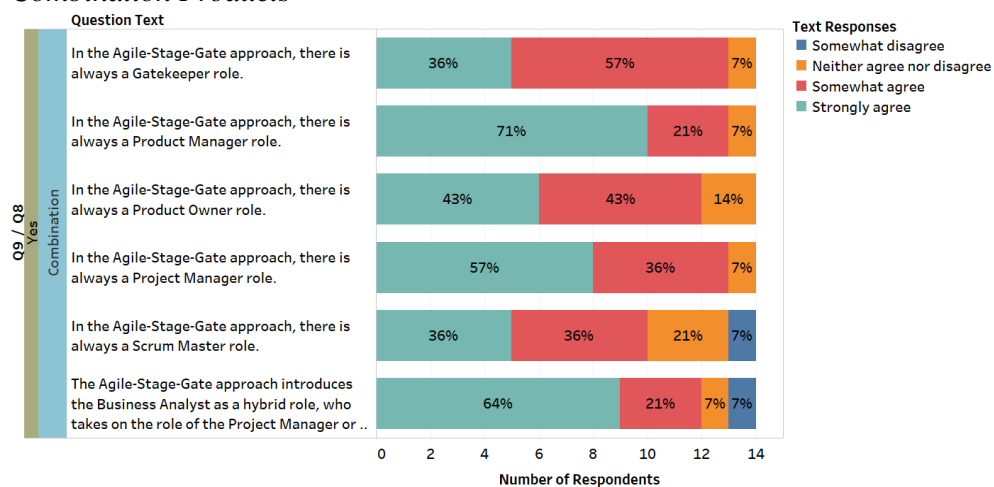
Figure 26. *Project Team Roles in the Agile-Stage-Gate Model for a Software Product***Figure 27.** *Project Team Roles in the Agile-Stage-Gate Model when Developing Hardware Products***Figure 28.** *Project Team Roles in the Agile-Stage-Gate Model when Developing Combination Products*

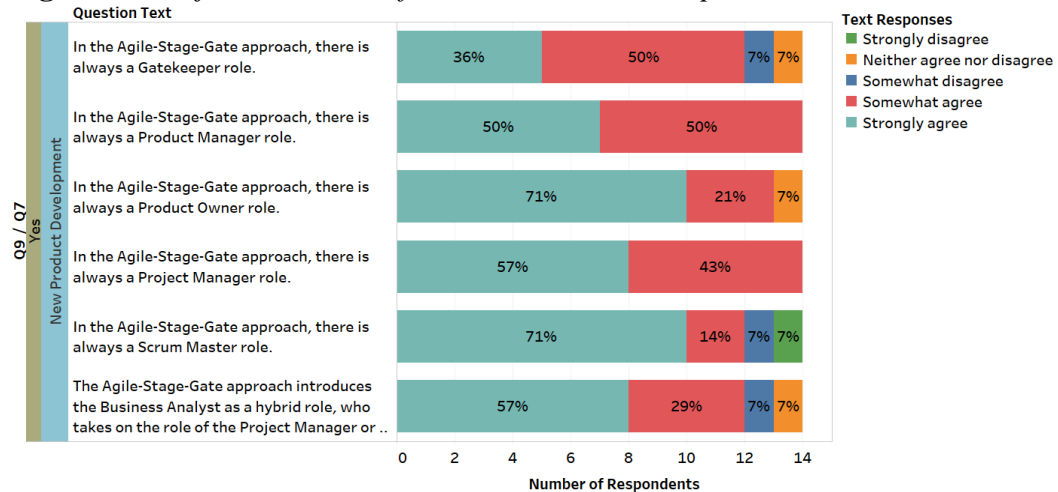
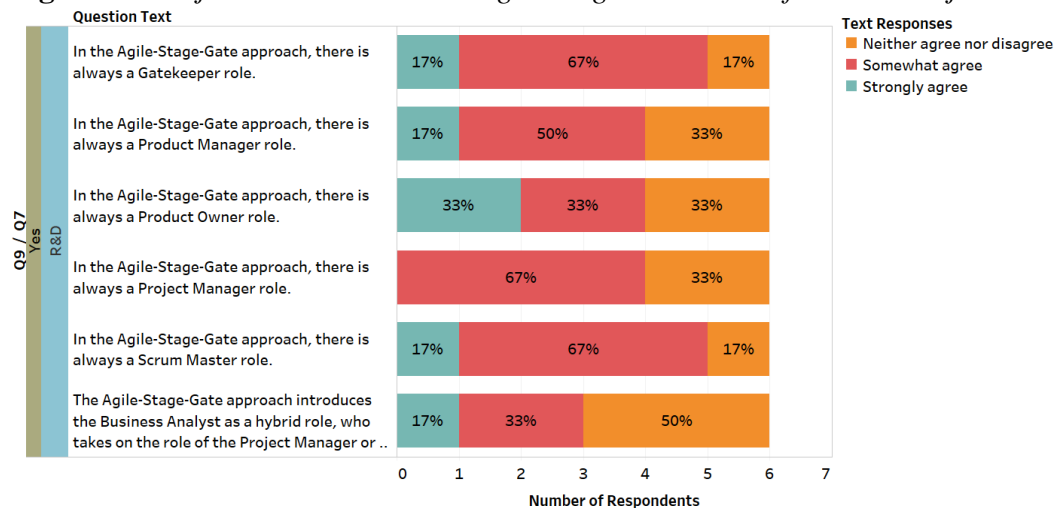
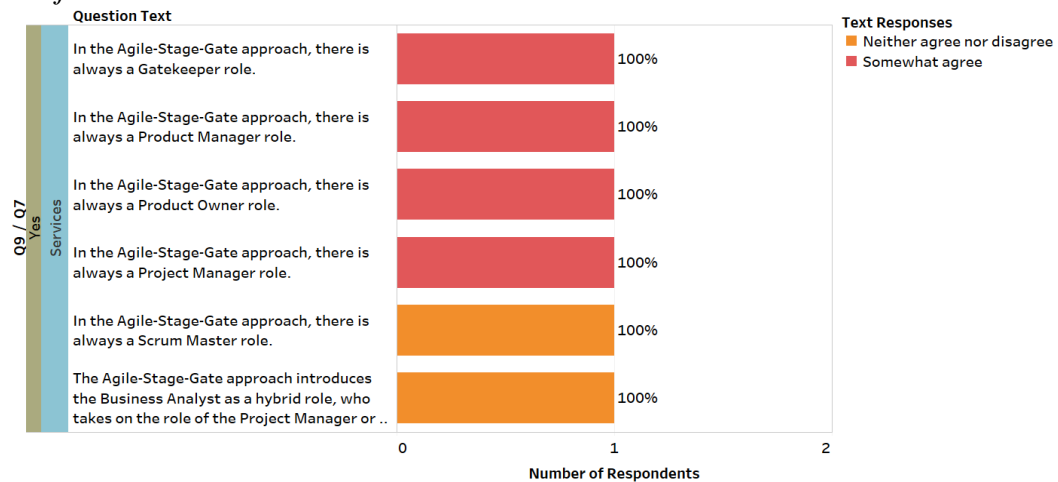
Figure 29. Project Team Roles for New Product Development**Figure 30. Project Team Roles in the Agile-Stage-Gate Model for R&D Projects****Figure 31. Project Team Roles in the Agile-Stage-Gate Model for Services Projects**

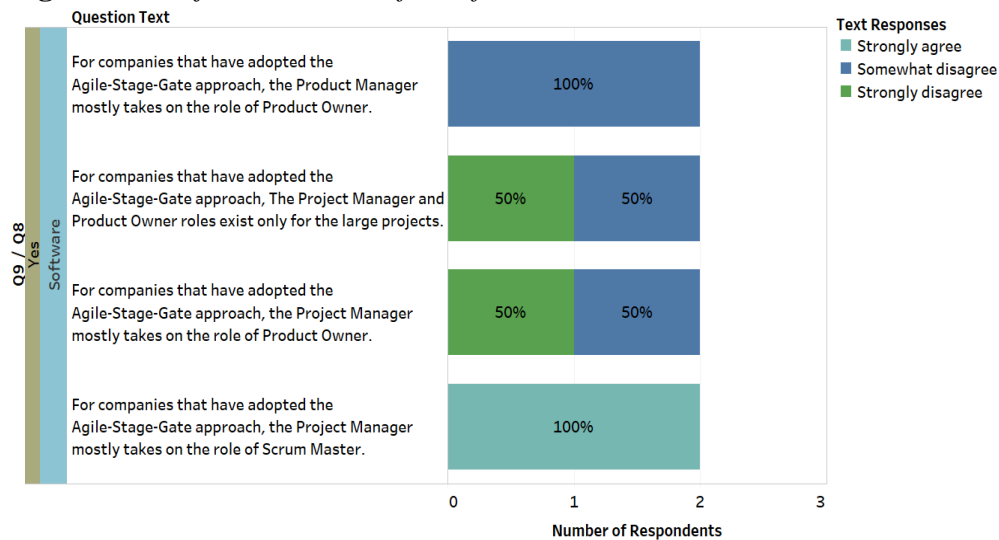
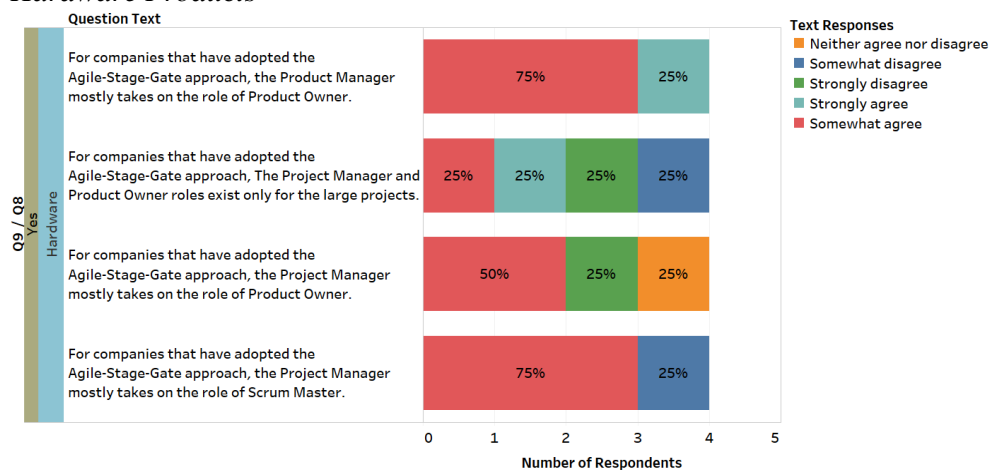
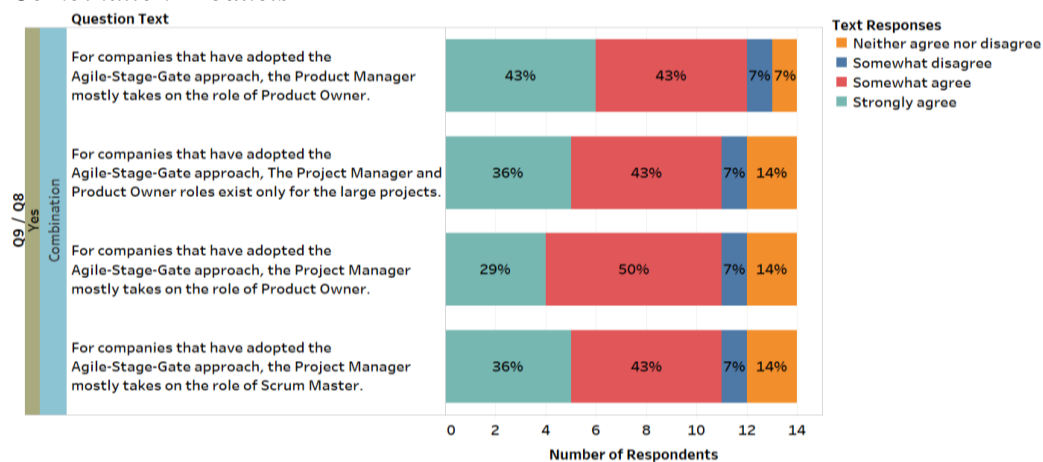
Figure 32. *Project Team Roles for Software Products***Figure 33.** *Project Team Roles after Adopting the Agile-Stage-Gate Model for Hardware Products***Figure 34.** *Project Team Roles after Adopting the Agile-Stage-Gate Model for Combination Products*

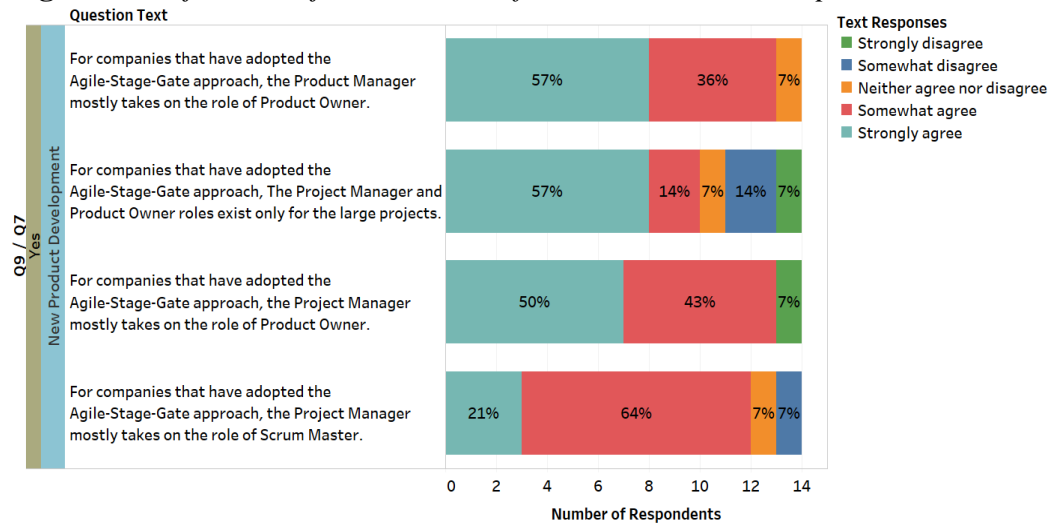
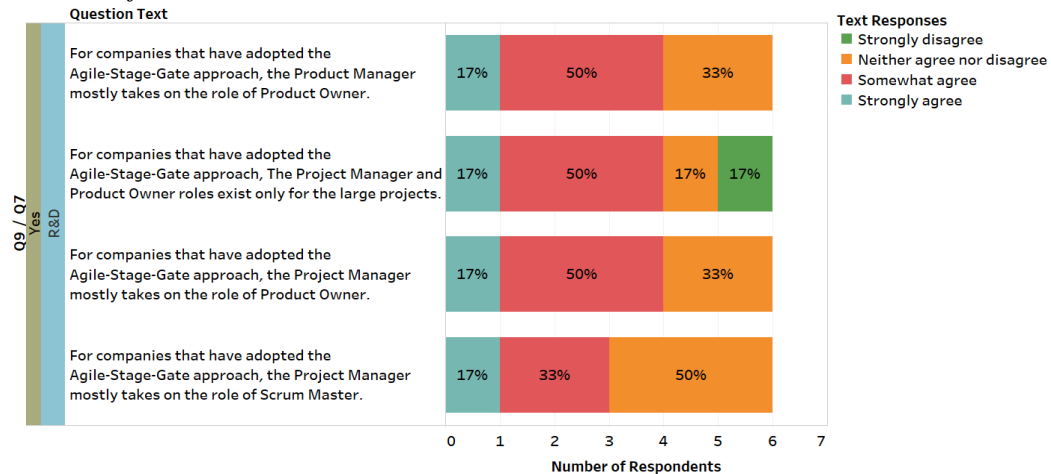
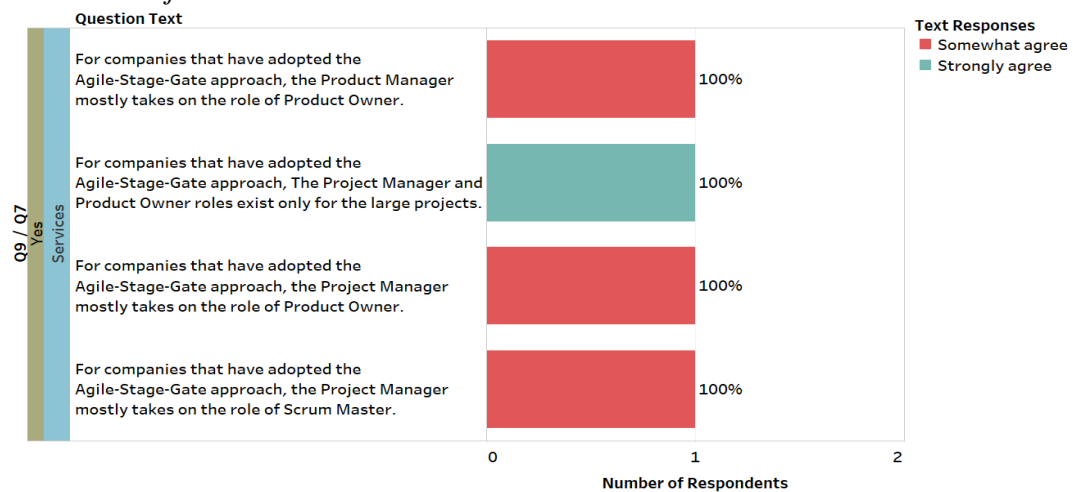
Figure 35. Adjusted Project Team Roles for New Product Development**Figure 36. Project Team Roles after Adopting the Agile-Stage-Gate Model for R&D Projects****Figure 37. Project Team Roles after Adopting the Agile-Stage-Gate Model for Services Projects**

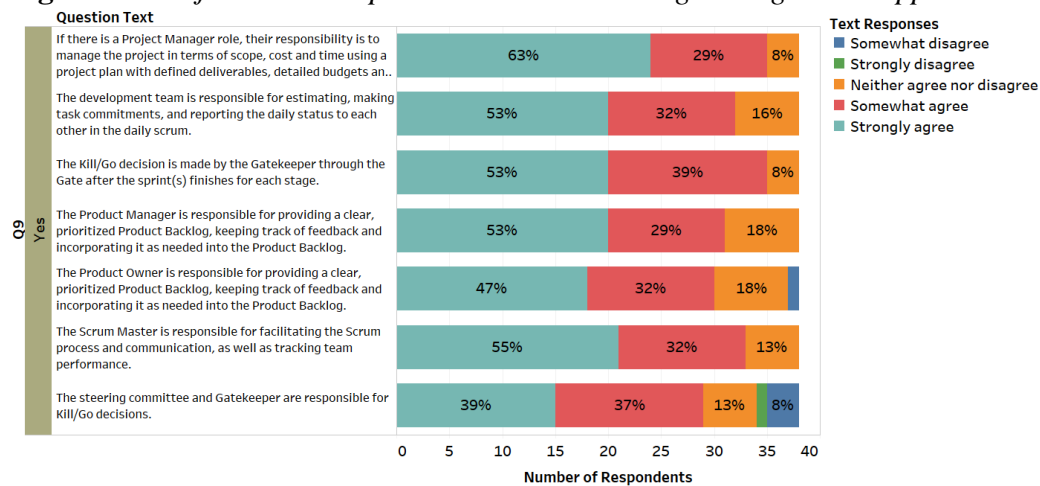
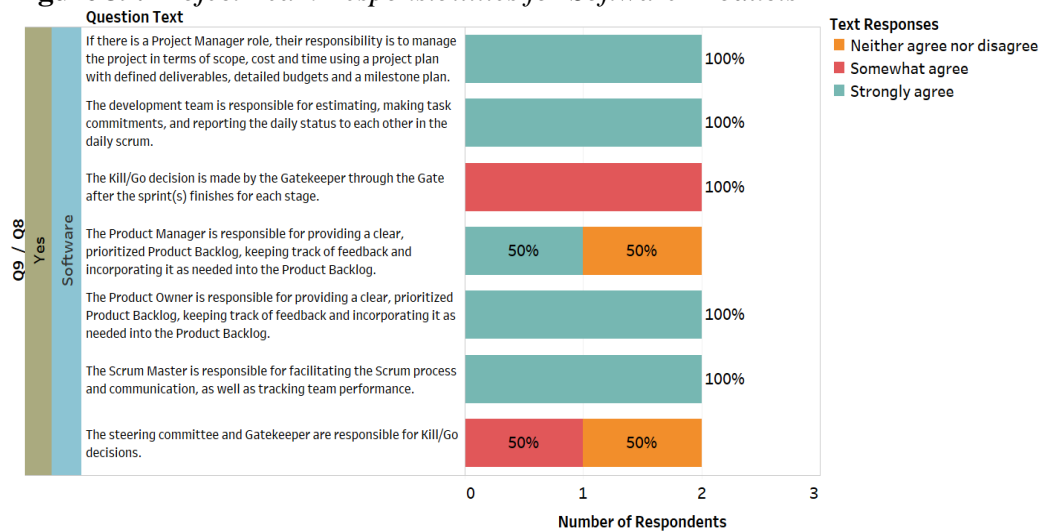
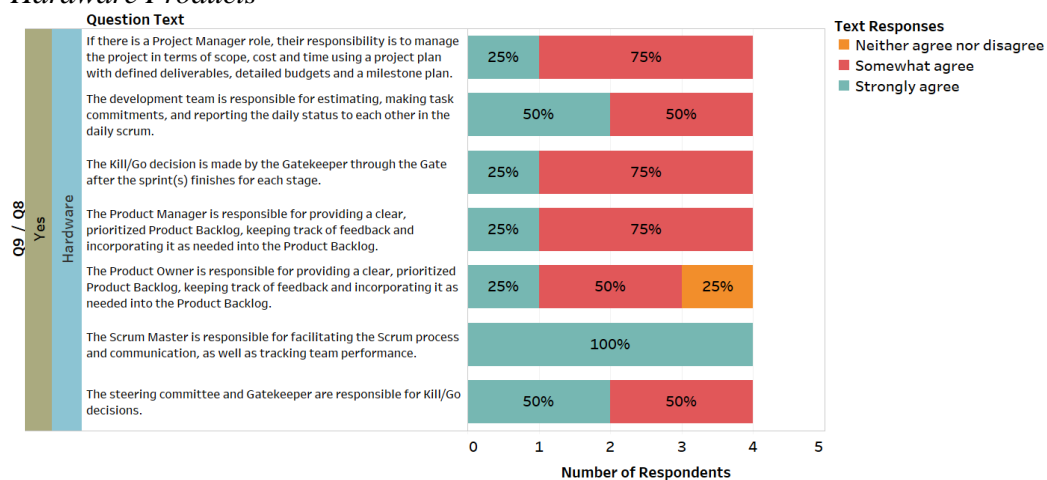
Figure 38. *Project Team Responsibilities within the Agile-Stage-Gate Approach***Figure 39.** *Project Team Responsibilities for Software Products***Figure 40.** *Project Team Responsibilities in the Agile-Stage-Gate Approach for Hardware Products*

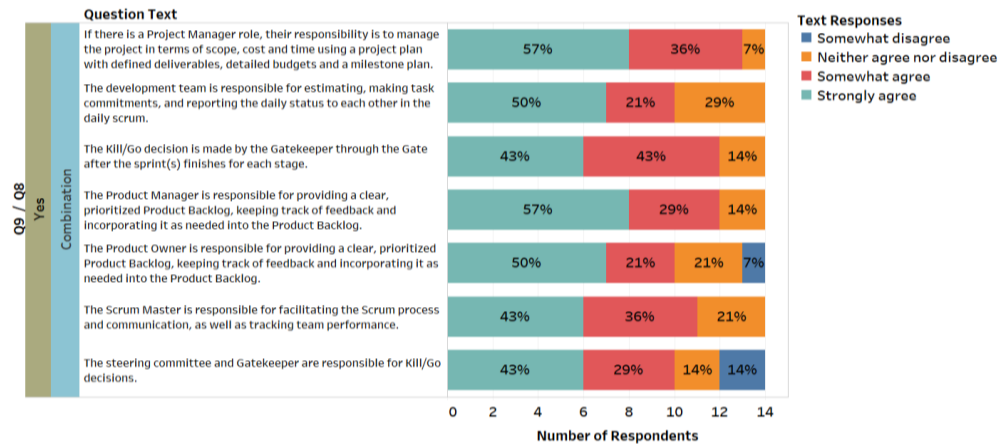
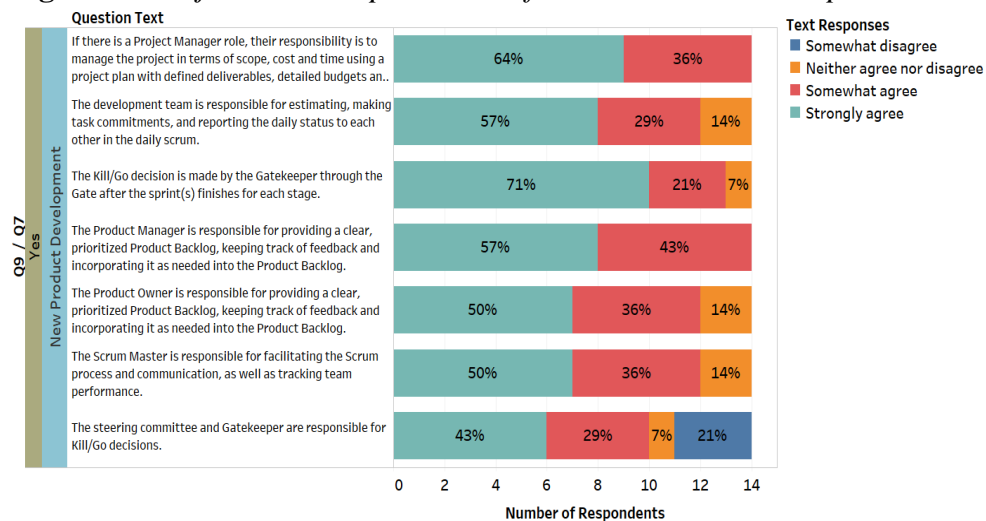
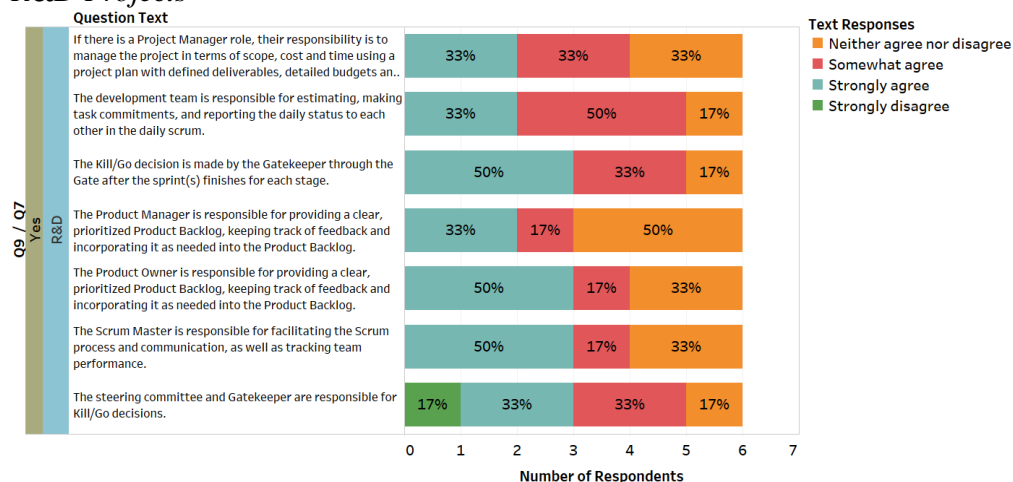
Figure 41. *Project Team Responsibilities in the Agile-Stage-Gate Approach for Combination Products***Figure 42.** *Project Team Responsibilities for New Product Development***Figure 43.** *Project Team Responsibilities in the Agile-Stage-Gate Approach for R&D Projects*

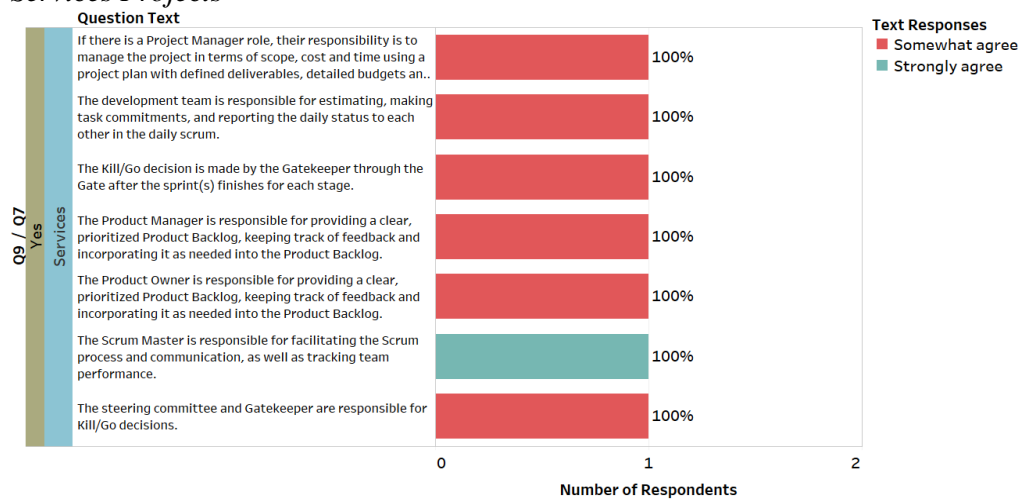
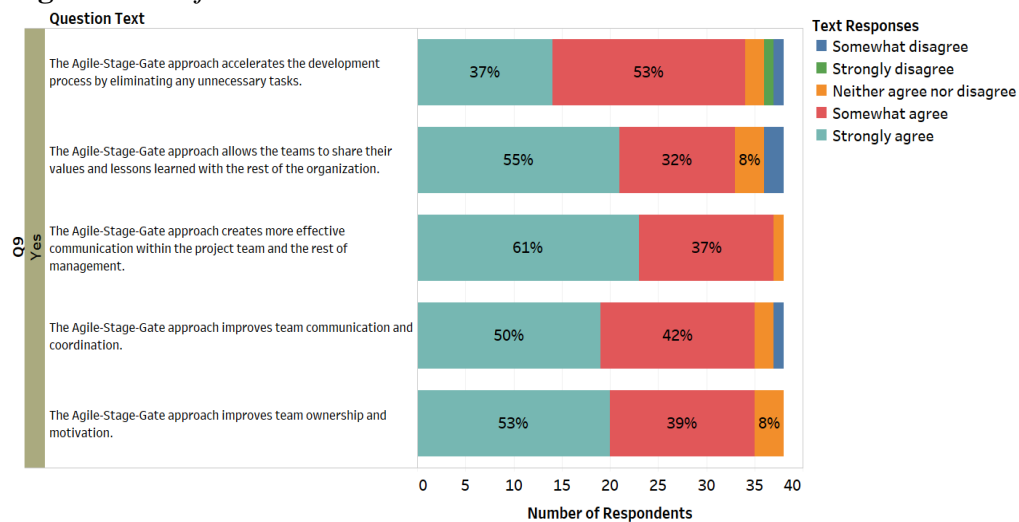
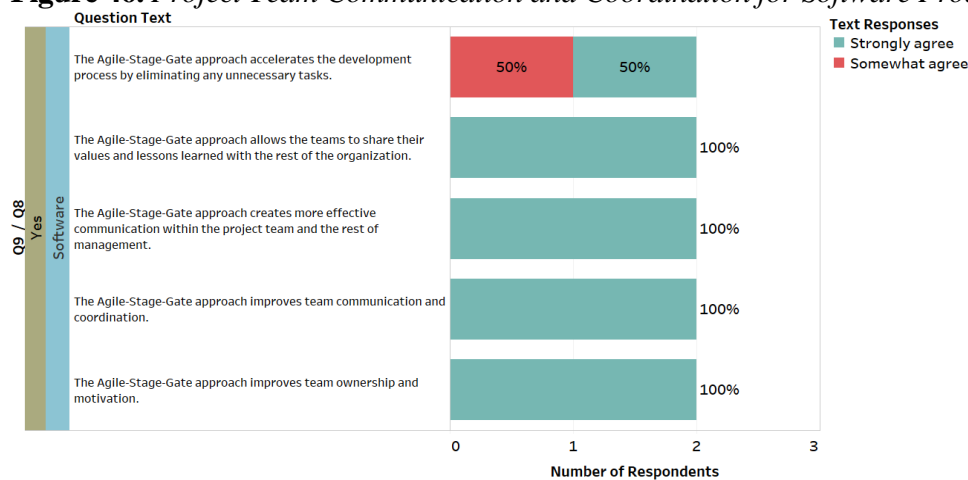
Figure 44. *Project Team Responsibilities in the Agile-Stage-Gate Approach for Services Projects***Figure 45.** *Project Team Communication and Coordination***Figure 46.** *Project Team Communication and Coordination for Software Products*

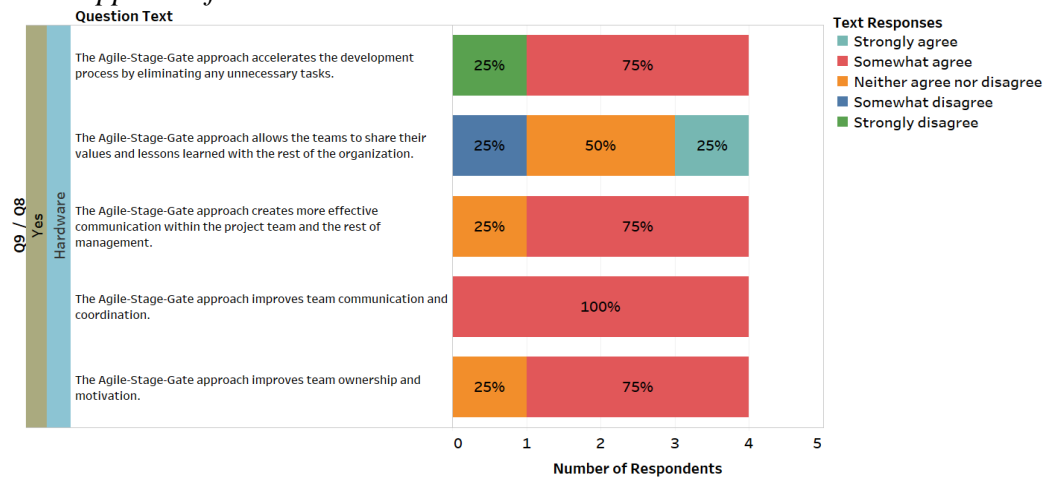
Figure 47. *Project Team Communication and Coordination in the Agile-Stage-Gate Approach for Hardware Products***Figure 48.** *Project Team Communication and Coordination in the Agile-Stage-Gate Approach for Combination Products***Figure 49.** *Project Team Communication and Coordination for New Development Products*

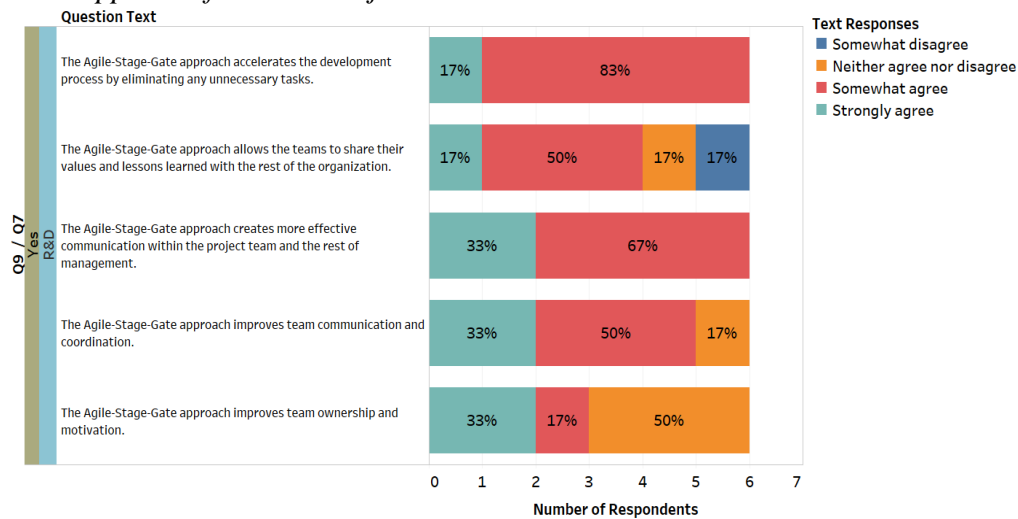
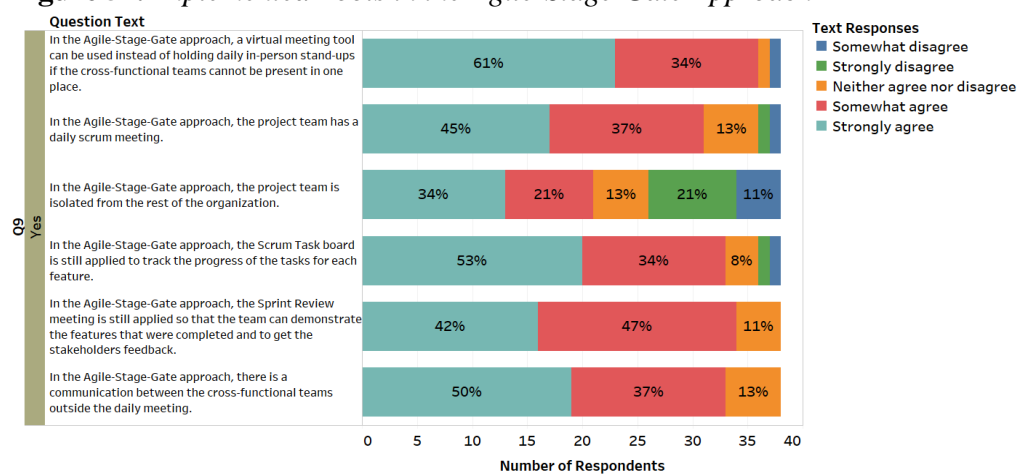
Figure 50. *Project Team Communication and Coordination in the Agile-Stage-Gate Approach for R&D Projects***Figure 51.** *Project Team Communication and Coordination in the Agile-Stage-Gate Model for Services Projects***Figure 52.** *Implemented Tools in the Agile-Stage-Gate Approach*

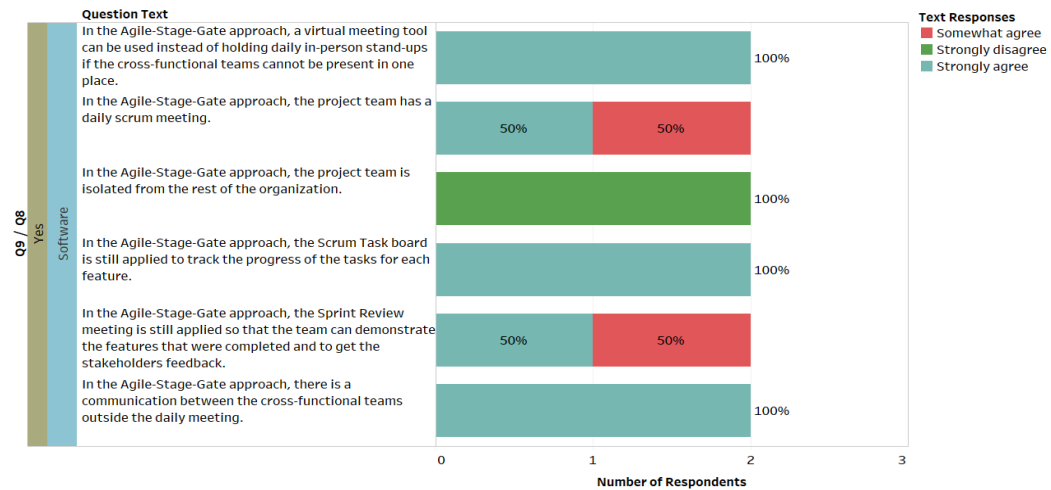
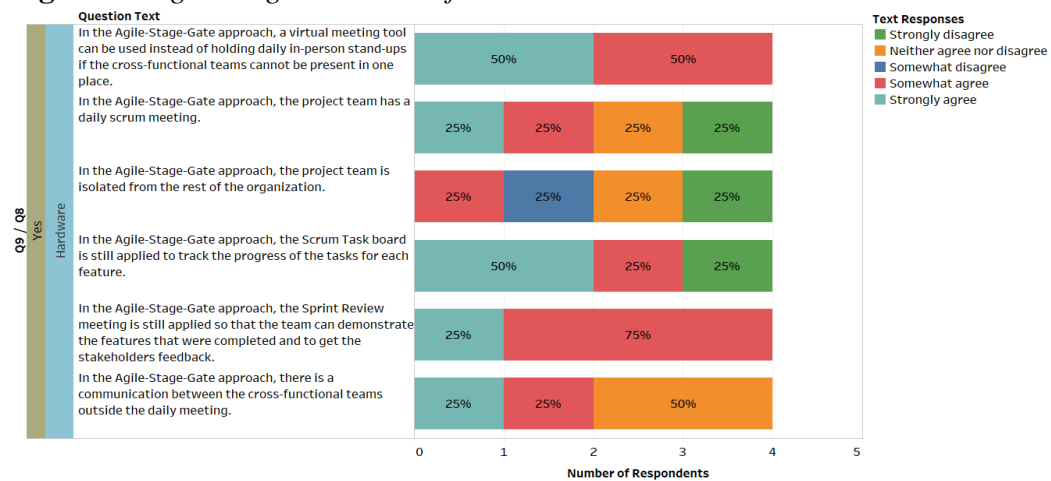
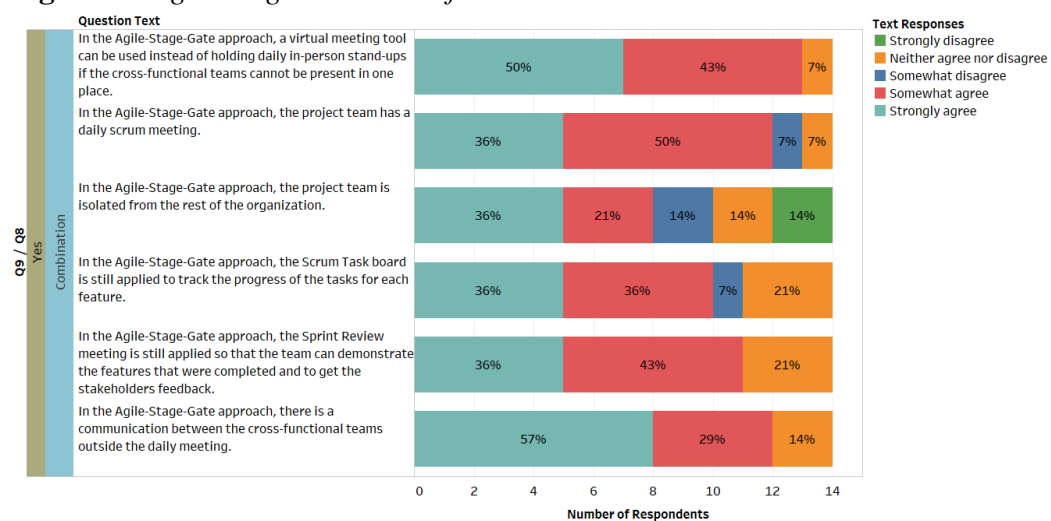
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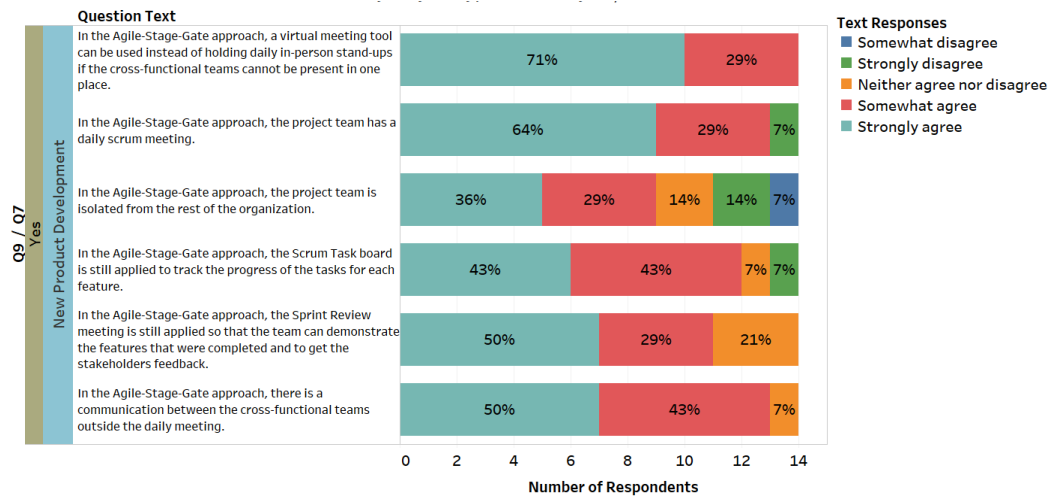
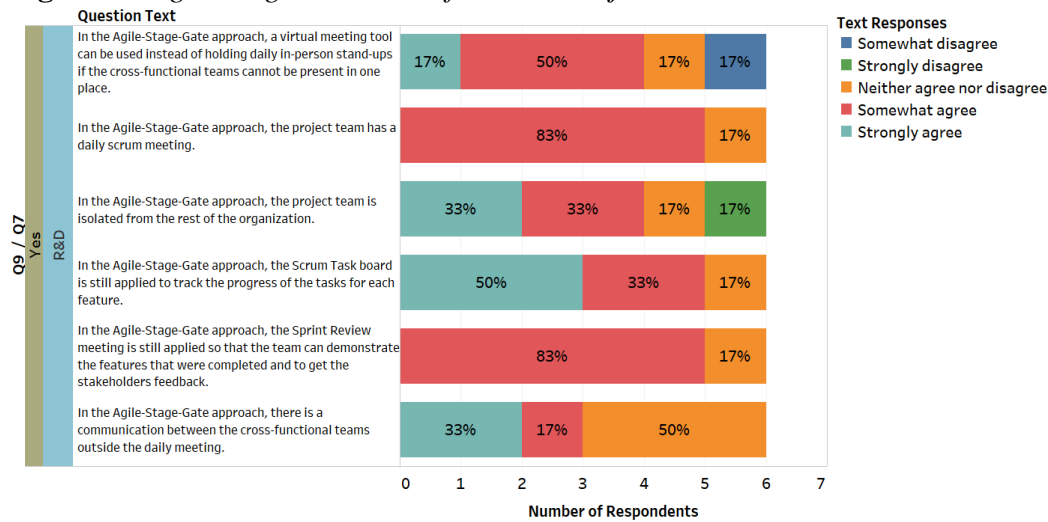
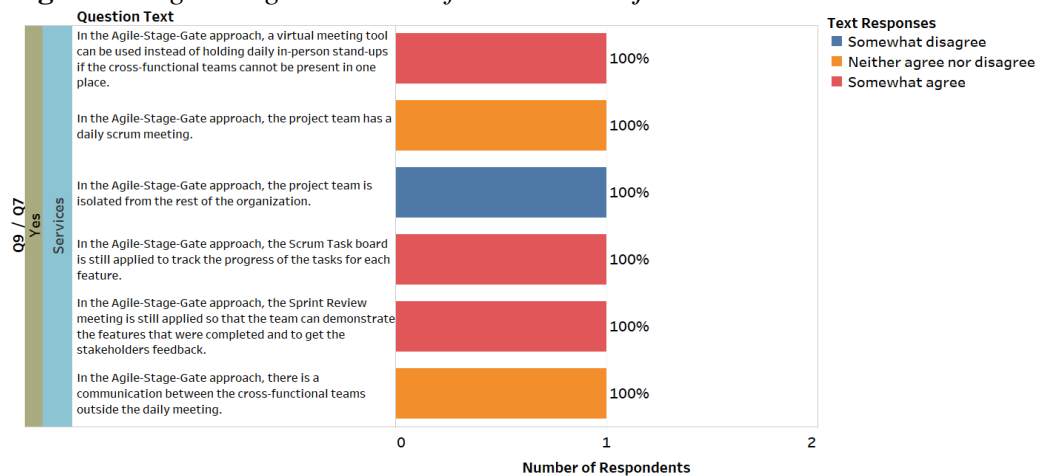
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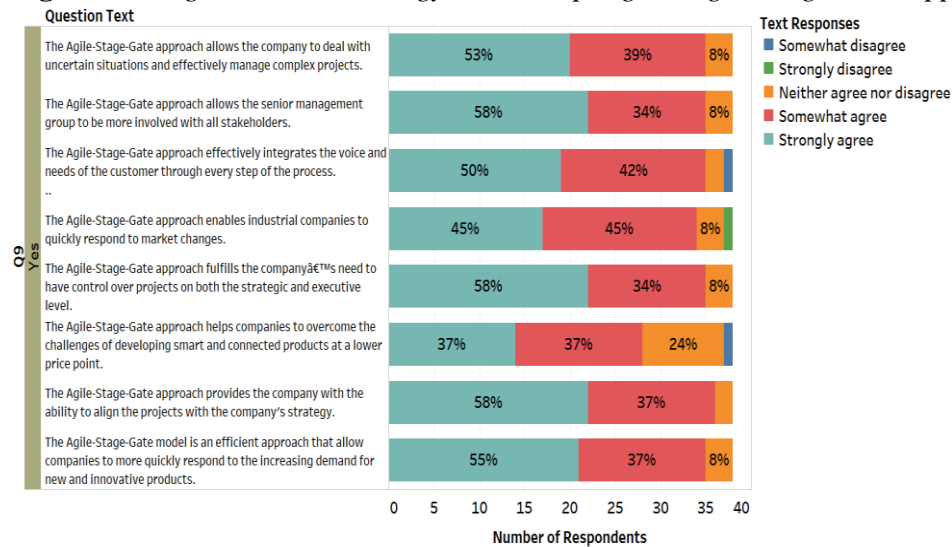
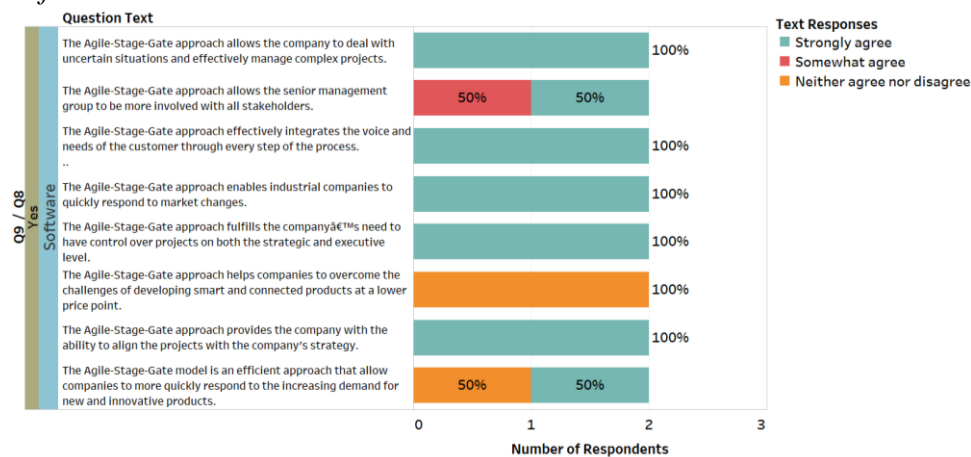
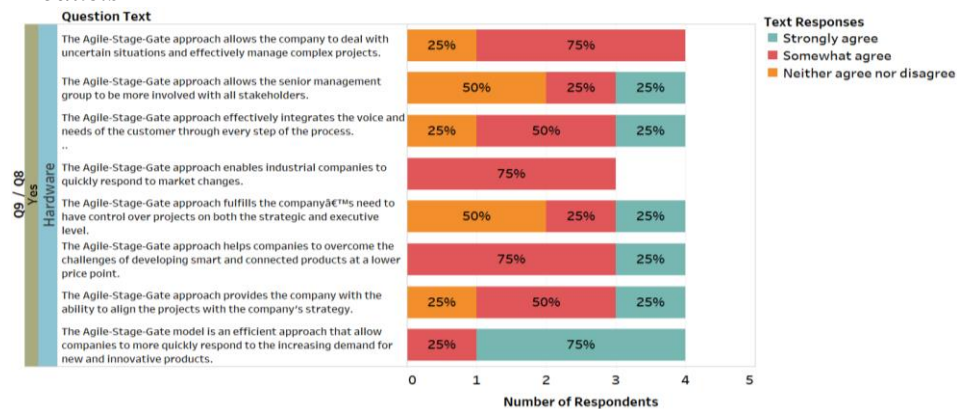
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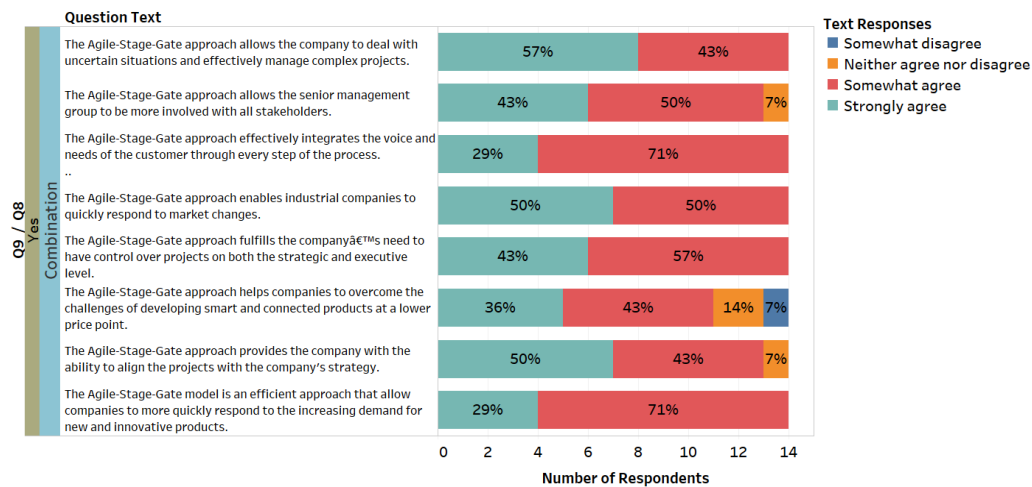
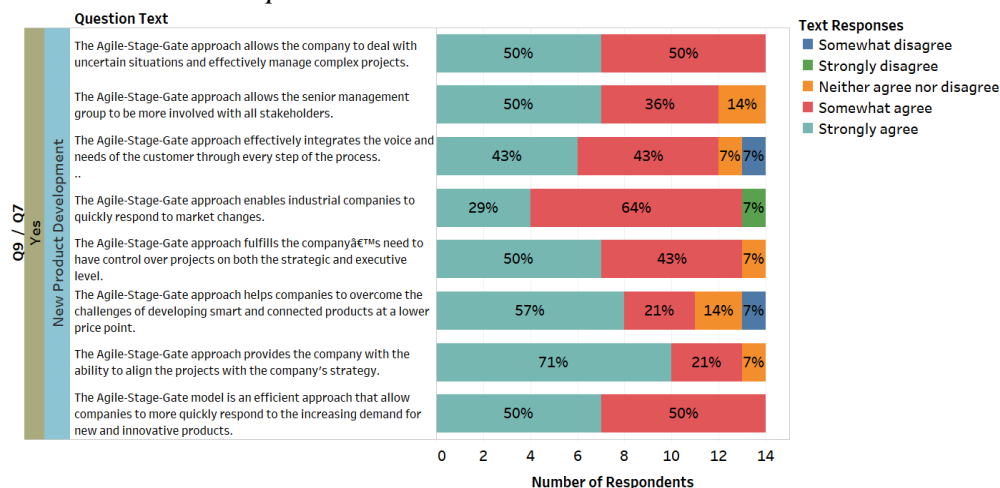
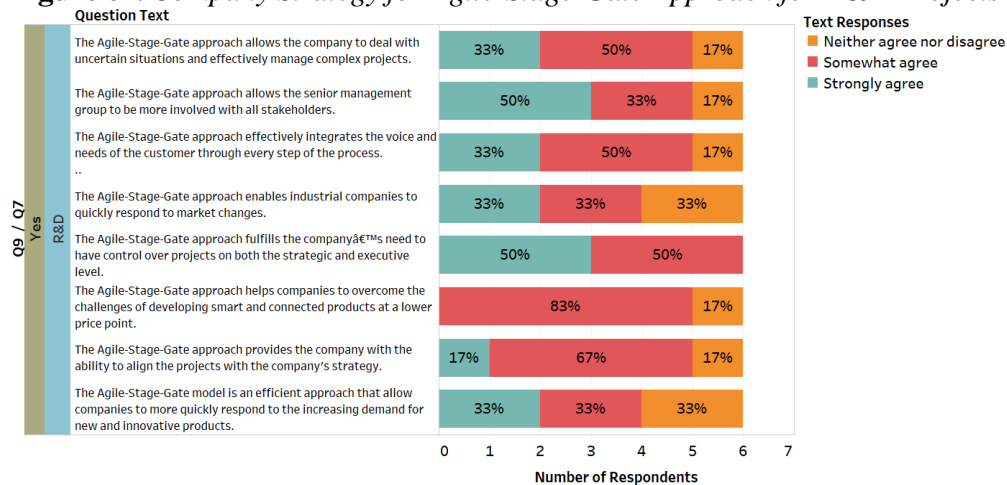
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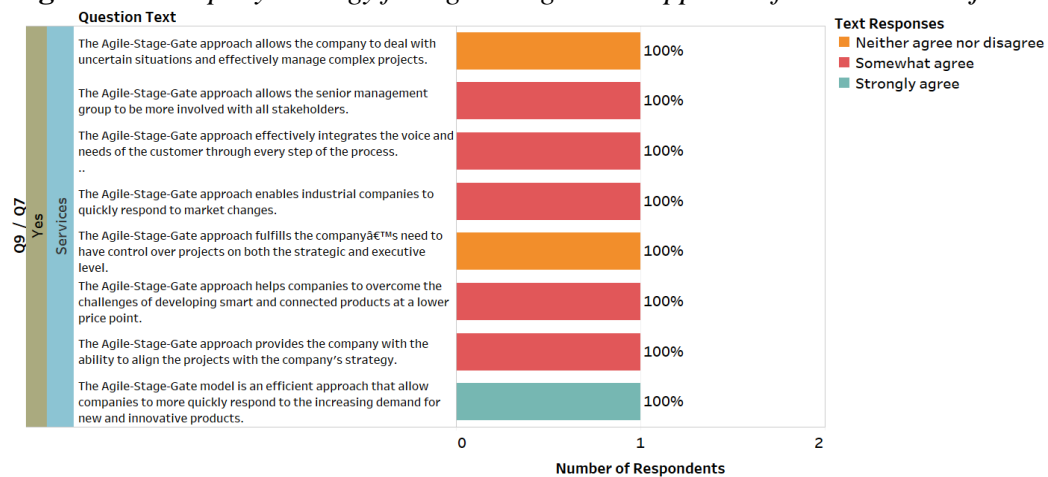
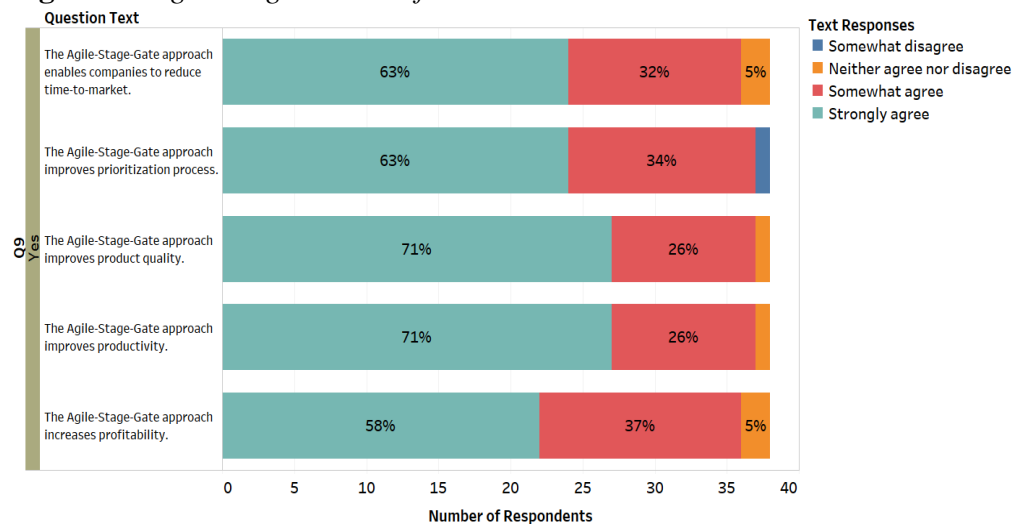
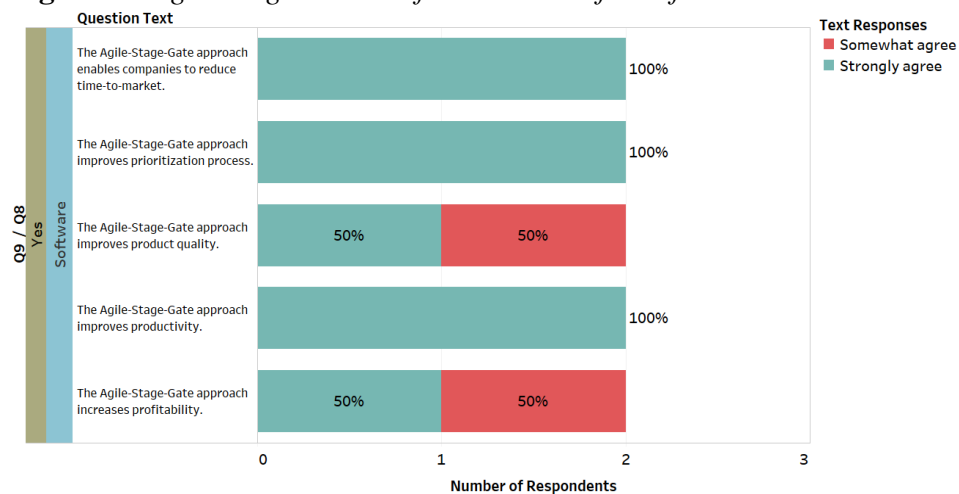
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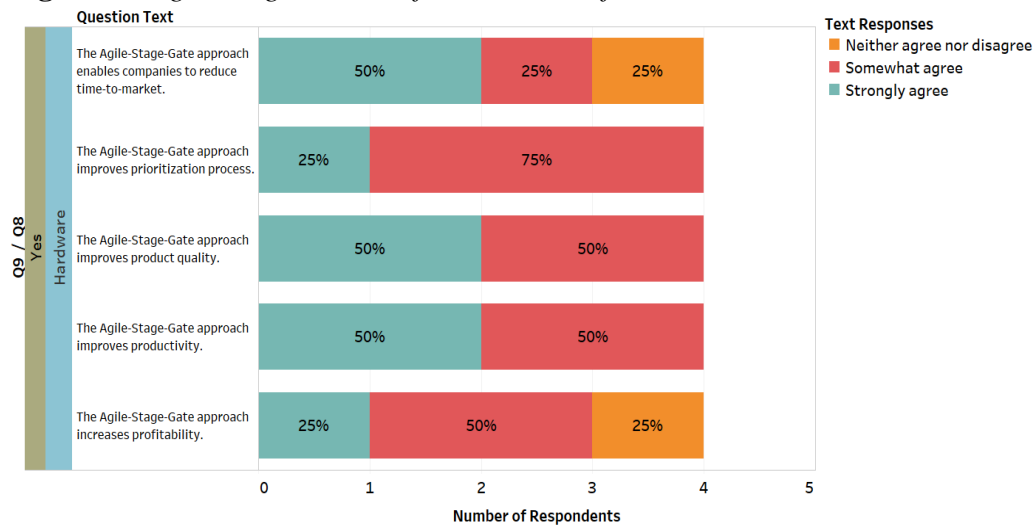
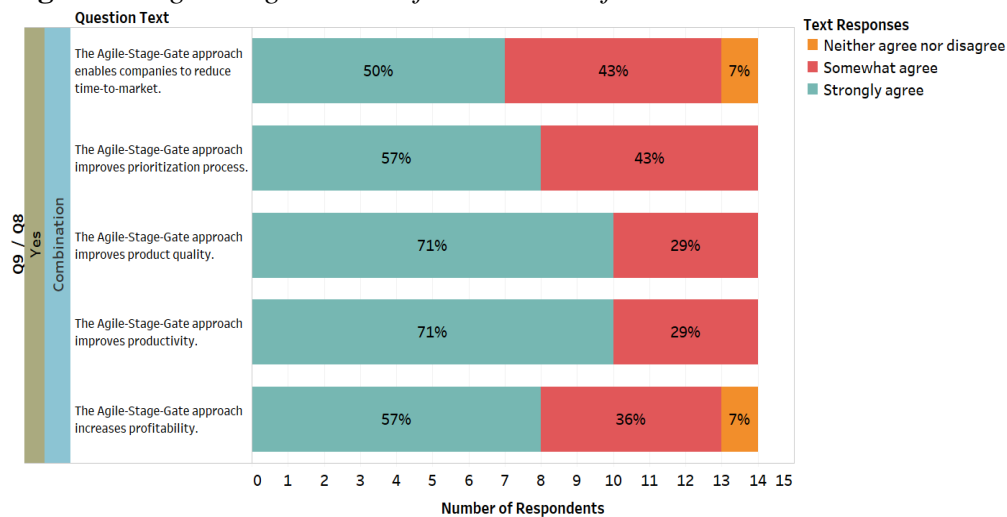
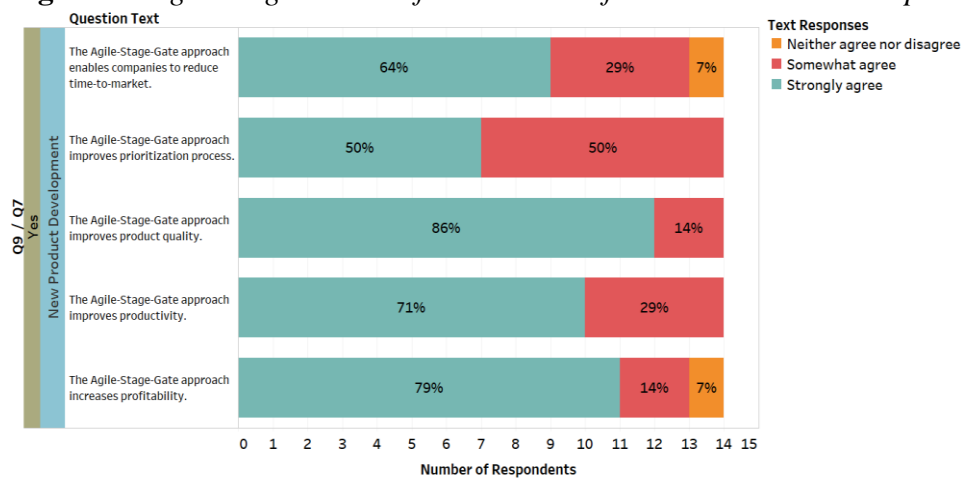
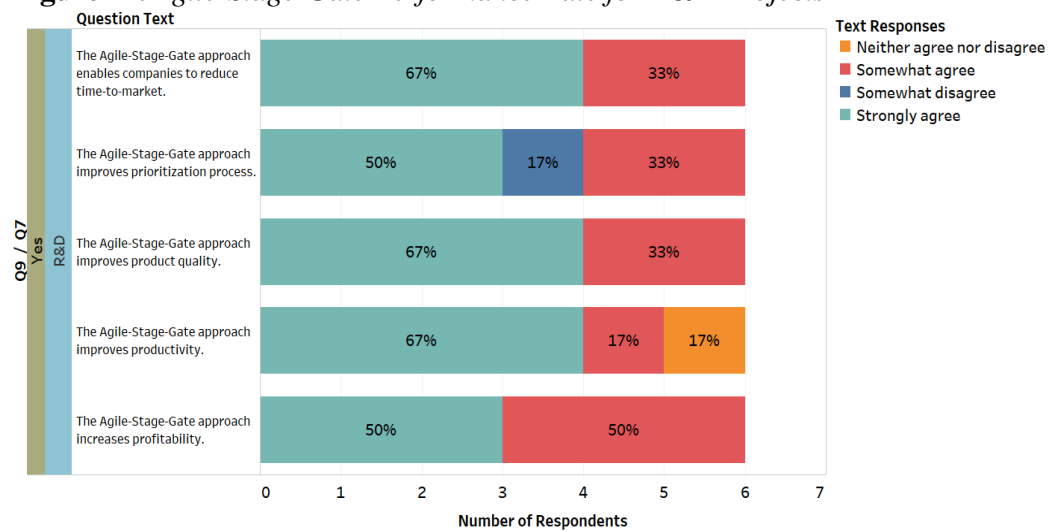
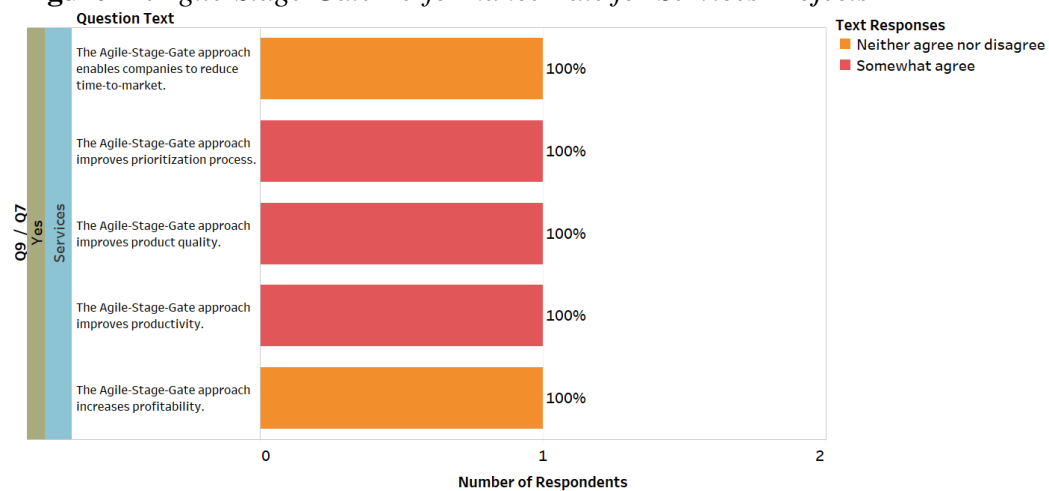
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Investigation of the Effect of Traffic Noise in Inspection of Urban-Level Noise: A Noise Analysis in Konya - Nalcaci Street

By Zeynep Ümmühatun Özen^{*}, Mustafa Tosun[±] & Enes Yasa[‡]

In this study, the effects of noise, due to the increase in population in urban centers, industrialization and land traffic, are evaluated on human health, indoor life standards, and auditory comfort. For this purpose, noise levels were recorded in Ahmet Hilmi Nalcaci Street, which is one of the densest streets of Konya. The recordings were performed at 14 different stations, three times a day and for 14 days. A "Testo 815" brand device was used for measurement and recording. The results of the measurements were evaluated according to international standards and domestic regulations, taking into account the situations where windows and doors, which constitute integrity and blanks in the envelope of a structure, are open. It was determined that the noise levels recorded at the stations are above the discomfort threshold. Settlement-and architecture-level measures to reduce and control noise are suggested in the study. It was determined that the most effective measure in this context would be isolation in structure envelopes. Types of walls generally used in the buildings around the street, which is the subject of the study, were determined and the sound penetration loss values for these walls were given. The sound penetration loss values were also compared to indoor noise limit values in certain measurement points and excessive noise values were presented in the study.

Keywords: Noise pollution, traffic noise control, environmental noise, urban level noise, Testo 815

Introduction

Noise has become one of the most important problems of our age and while it doesn't have a specific structure, it is defined as "unpleasant sound which is a source of danger for humans" or "polluted version of natural sounds". Noise is not defined by the quality of sound, it depends on our reaction to the sound.

Exemplified as all kinds of sounds that are disturbing, annoying, or that which hampers daily activities such as working, resting, and entertaining, noise includes all sounds that have high intensity, that are unpleasant or unexpected (Doelle 1972). Sources of noise can be classified into various perspectives. Noises, which can generate or spread in the air or solid environments based on the source of the sound, can spread from point, linear, or planar sources (Kurra 1997).

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The effect of noise on humans varies among persons and societies (Akgüngör and Demirel 2003). The negative effects of noise on humans start at 55–60 dB. The disturbances at these levels are noticeably increased by the noise level reaching 60–65 dB. If the noise level is above 65 dB, there are serious physical, psychological, physiological, and performance impacts on the person (OECD 1986).

Noise control is all controls and measures applied to minimize sounds of any origin, which are in the form of noise, and negative effects of these sounds, and also preserve user welfare and a productive environment for people. All of the methods such as changing the acoustics of the voice to provide a certain background noise level in the interior, reducing the duration of the effect, lowering it to an acceptable level, masking it with another voice that sounds pleasant or less disturbing are defined as noise control (Kurra 2009).

There have been many studies on ambient noise and its effects in the world and Turkey. Ho, et al. examined the effects of road coverage and tire deterioration on tire/road noise in their work (Ho et al. 2013). Freitas et al. investigated the effect of different road types, vehicle speeds, and traffic intensity on traffic noise in their work (Freitas et al. 2012). Praticò and Lédéb (2012) have studied the use of coatings to reduce traffic noise in their work (Praticò and Lédéb 2012). Ko et al. (2011) used a case study to assess noise impact in Chungju, Korea using CBS and noise maps (Ko et al. 2011). Naish (2010) created a noise management strategy for Australia's seven different local governments. In the study, the data presented in GIS format and the six-step method of traffic noise calculation were used (Naish 2010). Özyonar and Peker (2008) investigated the ambient noise pollution in Sivas city center (Özyonar and Peker 2008). Cho and Mun (2008) investigated the effects of surface coating types on vehicle noise to evaluate various road surface types by the Korean Highway Corporation (Cho and Mun 2006, 2008). Lede and Pichaud (2007), in a study conducted in 2007, the tire/road noise to Have examined the effect of temperature. Tire/road noise when outdoor temperature increases emissions are reduced (about 0.1 dB/1°C) (Lede and Pichaud 2007). Qadis and Alhory (2007) developed three models that predicted these parameters by analyzing the parameters affecting road traffic noise (vehicle type, road surface characteristics, horn usage status, vehicle speed, road width, etc.) (Qadis and Alhory 2007). Zannin et al. (2006), conducted noise measurements at 303 different locations in six city parks in Crubita, Brazil, and determined noise pollution classes of these parks according to the noise limit allowed by local law (Zannin et al. 2006). Nas and Bertay (2004) identified 189 points in intersections and main roads where traffic was concentrated, covering an area of 120 km² to prepare a noise pollution map in the Konya Town residential area where this study area is located and the maximum noise level (L_{max}) and the equivalent noise level (L_{eq}) (Nas and Bertay 2004, Özyonar and Peker 2008). Güremen and Çelik (2003) aimed to determine the noise levels of the individuals living in these regions and the effects of noise on various actions within the periods of the study of traffic noise levels and determination of traffic conditions at the 61 reference points on the main roads and junctions in 11 regions specified in Niğde (Güremen and Çelik 2003). Tang and Tong (2003) developed a new model, examining previous models

for traffic noise forecasting for sloping roads in free-flow traffic conditions (Tang and Tong 2003). Li et al. (2001) were able to predict the traffic noise value with the help of a GIS-based model, which was included in all the factors affecting the traffic noise (Li et al. 2001).

Harris et al. (2000) compared the traffic noise model with the Stamina model over noise measurements (Harris and et al. 2000). Wetzel et al. (1999) stated that in Germany there are many standards for modeling roadside noise propagation (Ko et al. 2011, Sandberg 2003). Bay and Güney (1998) performed a study on tire-road noise. In the result of the work done, it was seen that as the speed increases at all loads and measurement positions, the noise level increases significantly, with the highest noise level at all loads and speeds being at the front of the tire and the lowest noise level at the side. As the load is reduced at the front, the noise level is also reduced to a degree, and at higher speeds, it is observed that the difference is smaller (Bay and Güney 1998). Kurra (1991) studied the environmental problems in Istanbul and possible solutions for these problems. In his research, 13 sample zones were selected to portray the noise conditions affecting households in every region, and the effects of this noise (Kurra 1991).

Evaluating Ambient Noise

The negative effects of noise on human health, behavior, and effectiveness have been portrayed in many studies until our day. Increasing noise due to technological progress and population increase affects people at different rates according to situations and conditions within buildings, and the consequences of this influence can sometimes lead to serious problems. The European Commission has set some targets for the average environmental impact to be below 65 LAeq, never exceeding 85 LAeq, and not hanging 55 LAEQs in quiet areas, under the "Fifth Environment Action Program" launched in 1996. Towards this goal, the EU member states have accelerated their ongoing work on noise control and have established common guidelines for noise mapping and noise mapping for all settlements (EU Green Paper 1996).

Noise maps, which can be defined in the form of a plan, or a section, of acoustic information belonging to a specific region or a city, in detail, in the same system, with equal level curves, coloring system and/or numerical value, city, contain a lot of information that can be used in planning stages. In many developed countries, preparation of regional and provincial scale noise maps are attached much importance and while reporting the current situation with the help of said maps, other studies are performed to examine the changes to be caused by possible developments. Germany, France, Greece, Holland, Denmark, Portugal, Spain, The UK, and Sweden are among the countries where advanced studies were performed on noise maps while in Turkey there are quite a few studies in this area. Therefore it is not yet possible to evaluate noise maps within the framework of city information systems and make use of the planning decree (Demirkale 1996, Kurra 2000).

National Directive - Directive on Evaluation and Management of Ambient Noise

In the Directive on Evaluation and Management of Ambient Noise, which is in effect in Turkey, the articles related to maximum levels for noise generated from transportation and industry, are stated below (Table 1). Ambient noise criteria for highways; Article 18 - (1) Values regarding the level of ambient noise generating from highways and prevention of highway noise cannot surpass the limit values presented in Table 6; and values regarding light rail systems cannot surpass the limit values presented in Table 7 (Resmi Gazete 2008).

Table 1. *Highway Environmental Noise Limit Values*

Areas	Planned/Renewed/Repaired Roads			Existent Roads		
	$L_{gündüz}$ (dBA)	$L_{akşam}$ (dBA)	L_{gece} (dBA)	$L_{gündüz}$ (dBA)	$L_{akşam}$ (dBA)	L_{gece} (dBA)
Noise-sensitive uses such as education, cultural activities, health facilities, summer houses and camping sites	60	55	50	65	60	55
Household-sensitive areas in the areas where there are commercial buildings and noise-sensitive usages	63	58	53	68	63	58
Commercial places in the areas where there are commercial buildings and noise-sensitive usages	65	60	55	70	65	60
Industrial areas	67	62	57	72	67	62

Source: Kurra et al. 1993.

Where the light rail system passes underground, the maximum resonance time at 500 Hz should be 1.4 for the project target and 1.6 seconds for the acceptance while the station is empty (Table 2). Effective and feasible measures are taken taking into consideration the techniques of noise curtaining in places where light rail transportation system inside and outside the city passes through noise-sensitive areas (Resmi Gazete 2008).

Table 2. Environmental Noise Limit Values for Light Rail Systems

Underground Stations		Leg (dBA)	Above ground Stations		Leg (dBA)
Cashdesks, stairs, corridors		55	Platforms (1.8 m from platform edge)	For trains stopping and launching	70
Platforms (1.8 m from platform edge)	For trains stopping and launching	80		Passing trains	75
	Passing trains	85			
	Trains standing by in working condition	65		Trains standing by in working condition	65
In-station air conditioning system		55			
Ventilation chan		55			
Emergency ventilation fans in close volumes in stations (at 22.5 m)		80			

Source: Resmi Gazete 2008.

Noise Exposure Categories

Article 27 - (1) In planning station, below noise exposure categories are considered in the determination of suitable areas (Resmi Gazete 2008):

- A) Category A (<55 dBA in Ldaytime) Area: In planning decisions, precautions are taken to preserve present silence while taking into consideration, present or planned uses that are very sensitive to noise. The noise at the top level of this category is not at the discomfort level.
- B) Category B (55–64 dBA in Ldaytime) Area: The background noise level should be taken into account when planning permission is given to protect frequent and modest uses. Measures against noise are taken when necessary.
- C) Category C (64–74 dBA in Ldaytime) Area: Planning decision is not normally given. However, in cases where the public interest is necessary, if there is a need to permit due to the absence of a quieter place, measures against noise are taken while considering the background noise level.
- D) Category D (>74 dBA in Ldaytime) Area: No planning decision is made. The situation is examined in terms of noise-immune uses and permission can be given if the buildings can be arranged in such a way to block noise (Resmi Gazete 2008).

Noise Indicators Used in Noise Maps

Day-Evening-Night Level L_{gag} (L_{den}): Expression of daytime-evening-night levels through the formula given below (Resmi Gazete 2008).

$$L_{gag} = 10 \log \frac{1}{24} \left[\frac{L_{gündüz}}{12 \times 10^{10}} + \frac{L_{akşam+5}}{4 \times 10^{10}} + \frac{L_{gece+10}}{8 \times 10^{10}} \right]$$

In the formula, as defined in TS 9798 (ISO 1996-2), $L_{daytime}$ (L_d) is the energy average of weighted long-term sound level and it is determined based on the year's daytime periods.

$L_{evening}$ (L_e), as defined in TS 9798 (ISO 1996-2), is the energy average of weighted long-term sound level and it is determined based on the year's evening periods.

L_{night} (L_n), as defined in TS 9798 (ISO 1996-2), is the energy average of weighted long-term sound level and it is determined based on the year's night periods.

In the formula:

Daytime: 12 hours, including from 07:00 until 19:00.

Evening: 4 hours, including from 19:00 until 23:00.

Night: 8 hours, including from 23:00 until 07:00.

Highway Traffic Noise

Road noise caused by traffic is the type of noise most people are exposed to and most disturbed by. The fluctuations in the intensity of the noise during the day are seen, but the inconvenience caused by the continuous noise is quite excessive. Road transport from traffic noise, which can be considered a point source of sound in a variety of vehicles on the roads is an integrated power noise generated during their motion in the same moment and research has shown that 80% of the sound energy generated in urban residential areas are caused by traffic noise 80% of the sound energy generated in urban residential areas comes from traffic (Kurra et al. 1993, Pakman 1990).

The noise level in roadway noise measurements goes up to 105 dBA at a 7.5 m distance from the roadside. These values are above the comfort standards of people (Beranek 1974, Alexandre 1975). The main factors of the vehicle transportation noise generated by the operation of the vehicles and the result of the movements are noise from braking, noise from the contact of the wheels with the road surface, and aerodynamic noise caused by the vehicle. Factors affecting the level of noise perception on the road are; distance to the road, traffic volume, road level, type of road cover, the grade of road slope, size and type of vehicle, roadside restoration, and vegetation cover.

Traffic density, traffic composition (light and heavy vehicles percent), the type of traffic flow (batch or continuous flow), average speed, the type of the road coating, the slope of the road, curves and intersections on the road, the size of the engine, the vehicle's age, road width and retaining walls are factors that can be counted among reasons affecting noise levels in highways (Akgüngör and Demirel 2003).

As the number of vehicles increases, the transportation noise increases. Increasing traffic intensity on a road causes the noise level to increase logarithmically. For example, when a single-vehicle causes 64 dB of noise, 2000 vehicles per hour generate 66 dB and 6000 vehicles generate 71 dB of noise (Can et al. 2000).

On the other hand, the noise level varies according to the types of traffic vehicles. Noise caused by heavy vehicles, especially trucks, is more than other vehicles. One reason for this is the axle loads that they bear. In heavy vehicles, when axle load decreases from 2000 kg to 500 kg, the noise caused also reduces by 15 dB.

Also increasing vehicle speeds increase the noise generated. The reason for this is that at high speeds, the rubbing of the vehicle wheels with the road surface is more severe than motor noise. However, this noise increase due to speed is not significant in trucks. The noise levels caused by vehicle speed and type can also be calculated using a variety of empirical formulae.

Factors Affecting Traffic Noise

The noise originating from the traffic depends on the distance between the traffic (source) and the receiver, the land cover between the source and the receiver, the type of road cover on which the source moves, the meteorological conditions of the region, the traffic density in the region, the traffic composition of the road, noise suppressing and reflecting structures between the source and the receiver, traffic speed at the region, road slope, etc. For example, a 10°C temperature increase in a region examined for traffic noise results in a reduction in the noise level of about 1 dBA. Thus if the noise originating from road transport needs to be examined, full knowledge is needed on the factors above (EAPA 2007).

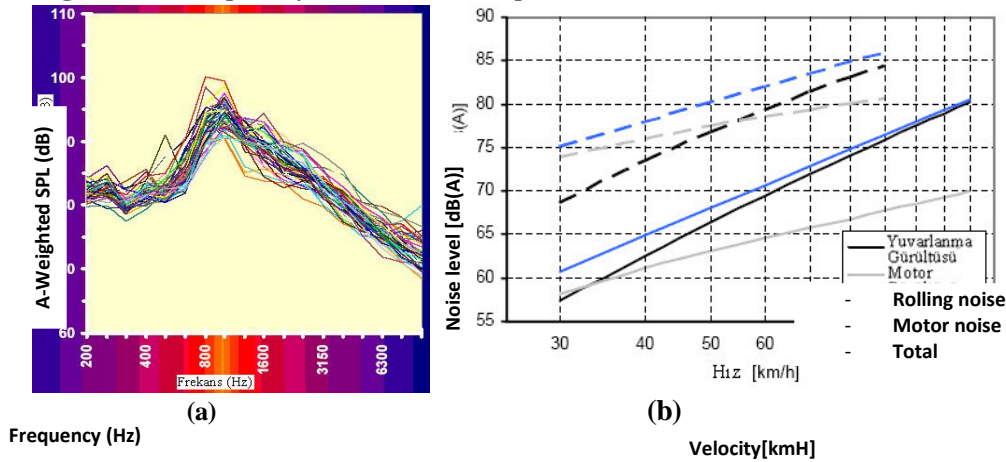
Components of Noise in Motor Vehicles

Passing vehicles generate noise due to many factors and these factors can be separated into three main groups, namely aerodynamic structure (wind-turbulence), vehicle motor and units, and tires/road. Aerodynamic noise is defined as the noise emission that occurs in the order of the turbulent airflow that occurs partially on the vehicle periphery during the movement of the vehicle. At low and medium speeds, this type of noise is often not a significant factor for off-road vehicles. The noise generated in the vehicle's engine and connected units comes from the engine, the drive system, the fan, the exhaust, and the transmission system. The third group is the noise generated during the rotation of the tires on the road surface

(Sandberg 2002). The noise components on the road and their different graphical values, the speed-dependent relationship, and changes of the heavy (intermittent) and light vehicles (permanent) wheel, motor, and total noises are given in Figure 1.

The effect of tire/road noise is increased within overall noise emission by vehicle acceleration. Noise from the car's engine is an important factor in urban roads where speed limits are around 30–50 km/h, while noise is ignored on intercity highways and motorways. Vehicle categories also have an important influence on noise levels. The sound pressure level of a passing vehicle increases along with the approach of the vehicle, reaching the peak point at the closest proximity. As you move away from the nearest point of approach, the sound pressure level decreases.

Figure 1. Examples of Road Noise Graphs



Source: Sandberg 2003.

- (a) Frequency spectrum of the noise generated by 50 different cars during their course at 90 km/h on a straight road (ISO 10844).
- (b) Speed-dependent level graphics of heavy (batch) and light (continuous) vehicles' tire, engine, and total noises.

Figure 1 contains various example graphics in connection to the relations which affect highway transportation noise. Figure 1a, which consists of two separate graphics, exhibits the frequency spectra of 50 vehicles, which are moving at 90 km/h speed on an arbitrarily constructed straight road at ISO 10844 properties. In graphic 1b, tire and engine noises of heavy and light vehicles can be observed together with levels of total noise produced by a vehicle in terms of speed.

Materials and Methods

In literature, methods such as "Building Research Establishment (Bre) Methods, Department of Environment (Doe), Cetur Method, Canada Mortgage and Housing Corporation (Cmhc), National Cooperative Highway Research

Program Report: The UK Method (CoRTN Procedure) German Method; RIs 90, Italian Method; Crn, Fhwa Method, Nmpb Routes 96" are used in relation to ambient noise calculation technics, highway noise prediction methods, and highway traffic noise calculation guides.

This study uses a calibrated Testo 815 brand noise level measurement device for respective noise level measurements. The device can pick up noise levels between 32–130 dBA. View of the measuring device is given in Figure 2, the specifications are given in Table 3.

Table 3. Specifications of the Testo 815 Manual Noise Measurement Device

Measurement range	+32 ... +130 dB
Frequency range	31,5 Hz... 8 kHz
Accuracy ± 1 digit	± 1.0 dB
Resolution	0.1 dB
Operating temperature	+40 °C
Storage temperature	-10 ... +60 °C
Battery type	9V block battery
Battery life	70 h
Weight	195 g
Dimensions	255 x 55 x 43 mm
Partial measurement ranges	30 ... 80 dB; 50 ... 100 dB; 80 ... 130 dB
Time settings	Fast 125 ms/Slow

Figure 2. View of the Testo 815 Noise Measurement Device



Choice of the Work Area

Studies in Konya have shown that noise generated from the traffic is at high levels (Aydın 2004). As can be understood from the number of vehicles passing between 07:00–19:00, presented in Table 4, the facts that it is the street with the most vehicles, there are mostly noise-sensitive household and commercial buildings in both sides of the street and it interconnects the north and south parts, that is, main accommodation and industrial zones, of the city, make Ahmet Hilmi Nalcaci Street one of the most suitable places to study (Figure 3).

Figure 3. View from Nalcaci Street**Table 4.** Traffic Dispersion and Highway Properties in Konya's Main Streets, according to Hourly Periods in 2013

Queue No	Street Name	Class	For 07:00–19:00 Period unit	All Road Span	Single Road Span (m)	Total Number of Lanes
1	Adana Çevre Yolu St	A	54,957	59.06	27.78	6
2	Beyşehir St	A	32,911	26.50	10.50	6
3	Karaman St	A	29,559	14.40	7.20	4
4	Yeni Sille St	A	32,911	43.00	20.00	4
5	Rauf Denktaş St	A	35,357	20.00	9.00	6
6	Hilmi Nalcaci St	A	69,928	28.70	9.60	6

Source: Konya Metropolitan Municipality 2013.

The area of the study zone is approximately 16 sqm and its length is 2.1 km. According to the information taken from Konya Metropolitan Municipality, road features of Nalcaci Street are given in Table 5.

Table 5. Road Characteristics of the Study Area

All road span	28.70 m
Single Road Span	9.60 m
Total number of lanes	6
Number of lanes	3
Lane span	3.20 m
Number of directions	2
Traffic island	9.50 m
Length	2.10 km
Number of intersections	4

Source: Resmi Gazete 2008.

The beginning of Nalcaci Street (south) is Vatan Street and the end (north) is Yeni Istanbul Street. There are 4 intersections between the beginning and ending of Nalcaci Street. These junctions are shown in Figure 4.

Figure 4. *Intersections in Nalcaci Street*

Existing Situation and Evaluation of the Current Situation in terms of Noise of the Study Area

The criterion of "Discomfort" has been established to determine the extent to which the physical characteristics of the noise and subjective factors have been assessed, the influence of the individual and the society. Evaluations made to identify the physical characteristics of the noise and to determine the shape and size of the effects are gathered under two main headings as measurement and estimation methods. The measurement methods from these evaluations include the process of making traffic noise records for the determined traffic conditions, using the appropriate measurement techniques in the course of a specified period, inspecting the changes according to time during this period, making analyzes, and assessing them with the standardized levels accepted for the situation.

Noise, being physically unstable and physiologically disturbing and defined as "undesired sound", arises in two different conditions as indoor environment and noise caused by an external environment. Nalcaci St is one of the major sources of noise in the context of externally induced noise. At the same time, there are many buildings and areas around the Nalcaci St that cause external noises.

Main sources of noise affecting the formation of large noise pollution in the region are traffic-transport noise, land transportation, industrial noises in the immediate vicinity, and ongoing construction noises.

Table 6. *Coordinates of Measurement Stations*

Station no	Coordinates	
	X	Y
1	36454898	4192845
2	36454917	4192331
3	36454915	4192422
4	36455111	4192768
5	36455106	4192769
6	36456904	4208899
7	36455327	4193164
8	36455395	4193276

9	36455556	4193398
10	36455547	4193480
11	36455636	4193538
12	36455019	7192641
13	36455546	4193481
14	36455795	4193921

Figure 5. Locations of 14 Measurement Points on Satellite Photographs



Traffic Noise Measurement Stations (Measurement Points) in the Study Area

In Konya city center, to determine the noise levels caused by traffic in Nalcaci Street, 14 measurement stations were determined near intersections of junctions and connection roads where business places and traffic are concentrated on the street, and especially for buildings with different usage purposes. Coordinates of the measurement stations, where noise measurements were performed, determined using a hand-held GPS receiver of Magellan Explorist 400. The coordinates of determining measurement stations are given in Table 6.

Figure 5 shows the location of the measurement points on Nalcaci Street on satellite photos and the usage areas around these points.

The reasons that the measurement points were selected in hospitals, housing, schools, hotels, and dormitories is to select where the people in the interior should be least affected, as well as areas containing the large number of people working in large numbers.

Performing Traffic Noise Measurements in Nalcaci Street

In the interior and exterior space measurements, the microphone should be 1.2–1.5 meters above ground (TS 9798 1992). In exterior space measurements, it is recommended to keep the microphone at least 3.5 meters away from the nearest reflective surface, to minimize potential reflection effects. If the purpose is to measure the level of noise a building is subject to, it is recommended to place the microphone at 1 or 2 meters away from the related front of the building (TS 9798 1992). Figure 6 shows microphone location in exterior spaces. While Kaushki et al. (2016) performed measurements at 1.5 m height, Onuu and Leong performed theirs at 1.2 m height (Sandberg 2003, Baaj et al. 2001). Dursun and Özdemir (1999) performed their measurements at ear level (165–180 cm from above the ground) (Kalıpcı 2007).

Figure 6. Location of Point Measurement



Noise measurements were made with the Testo 815 brand noise meter on December 14, 2015 (at the measuring point) at the 14 measurement stations whose coordinates were taken. The measurements were made at the location shown in Figure 6 at a distance of 2.00 m behind the roadside edges of the pavement at the noise level or the edge of the junction and at a height of 1.5 m above the ground and in the absence of precipitation.

On Nalcaci Street, evening measurements were made between 08.00–09.30 hours in the morning, between 12.00–13.30 noon, between 17.00–18.30 hours, during weekdays where the noise of motor vehicles is intense. Seven measurements were made at one measurement station in the morning, noon and evening, and 21 measurements were made at each measurement station in total.

Results and Discussion

Traffic Noise Measurement Results in Nalcaci Street

Measurement times and values for traffic noise in Nalcaci Street, where the field study was performed, are given in Table 7.

Table 7. *Nalcaci Street, Traffic Noise Measurement Values*

Noise level (dBA) measured at measurement points													
5	6	7	8	9	10	11	12	13	14				
79.0	79.8	77.4	73.5	72.5	69.7	71.4	69.7	70.9	70.3				
80.8	81.1	73.9	76.2	70.9	72.1	69.2	70.6	71.2	68.4				
79.4	78.0	79.7	70.4	76.4	70.9	69.9	74.3	73.6	67.5				
75.1	79.1	75.6	69.9	73.6	69.7	71.5	72.1	73.9	67.9				
78.2	78.8	76.7	71.7	77.8	71.3	70.9	73.1	72.6	68.2				
77.4	77.2	71.3	75.9	74.6	70.6	71.6	72.6	74.3	65.2				
76.2	78.3	79.6	73.0	71.4	70.9	68.9	72.0	73.6	64.8				
72.4	74.9	80.8	73.0	72.5	71.5	72.6	71.3	71.3	64.2				
74.3	77.2	77.3	72.7	73.2	67.9	72.4	75.4	72.5	67.9				
75.5	71.5	80.1	74.8	71.7	71.9	70.9	74.8	74.7	63.7				
76.0	72.0	79.8	72.7	72.3	71.5	65.7	74.3	73.5	66.5				
70.8	73.2	80.7	71.0	70.6	69.4	68.4	70.8	71.9	62.8				
72.3	76.3	72.8	71.1	71.8	70.4	68.6	67.8	73.5	66.8				
81.0	73.8	77.6	71.1	73.0	69.0	70.3	75.5	70.7	63.5				
78.8	76.5	72.4	76.1	74.5	72.4	72.6	70.8	72.3	66.6				
76.6	73.5	76.8	75.7	73.9	67.0	68.5	72.6	72.5	67.5				
78.2	81.9	70.8	73.3	78.6	70.9	69.4	70.6	70.5	66.5				
77.5	74.1	79.4	78.2	76.1	67.1	68.6	69.9	72.0	67.5				
75.5	77.8	78.9	76.6	74.7	68.1	62.6	70.7	71.5	68.8				
78.9	74.8	71.4	74.4	71.1	68.7	65.6	72.3	70.6	67.0				
77.7	79.0	72.4	73.8	75.3	70.0	63.4	71.9	73.3	66.2				

Time of measurement				
	1	2	3	4
	08.00	78.1	77.7	83.5
	08.15	73.6	79.9	79.1
	08.30	75.0	81.1	79.7
	08.45	74.0	74.4	78.9
	09.00	80.5	74.4	81.6
	09.15	78.6	79.6	79.3
	09.30	78.8	74.5	77.8
	12.00	81.0	77.0	79.7
	12.15	78.4	79.7	83.4
	12.30	79.4	77.9	77.4
	12.45	78.1	81.0	81.1
	13.00	78.8	76.2	81.2
	13.15	82.5	79.8	80.7
	13.30	78.8	75.3	79.0
	17.00	76.6	73.6	74.6
	17.15	79.3	76.6	75.2
	17.30	76.4	87.7	75.2
	17.45	77.9	82.1	76.9
	18.00	77.3	74.7	78.9
	18.15	75.1	85.1	76.7
	18.30	78.3	85.8	80.6
Time	MORNING (08.00-09.30)		NOON (12.00-13.30)	
			EVENING (17.00-18.30)	

Evaluating Measurement Values in terms of Affected Spaces and Legislation

As evaluation criteria, the interior space noise limit values are given in Table 8 below, which are presented in line (a) of Article 20 published in the "*Directive on Evaluating and Management of Ambient Noise*", prepared by the Ministry of Environment and Forestry, published in the Official Gazette dated 01.07.2005 and no 25862.

Table 8. Interior Noise Level Limit Values

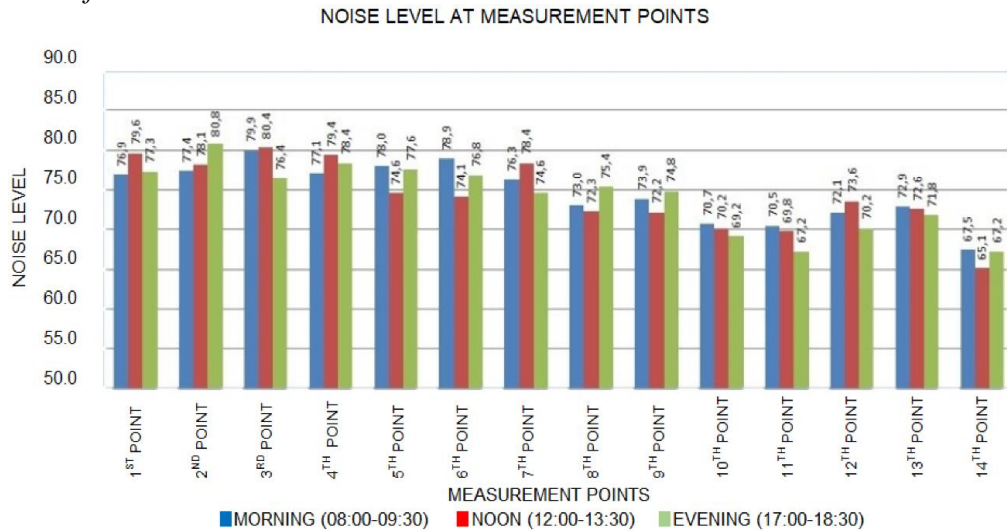
Usage Area		L _{eq} (dBA)	Time (h)
Health Facilities	Inpatient treatment institution(s), dispensary, polyclinic, nursing homes and rest homes	35	Continuous
	Resting and treatment rooms	25	Continuous
Education Facility Areas	School classes, interiors of pre-school buildings, laboratories, private education facilities,	35	During class
Tourism Accommodation Areas	Hotels, holiday villages, guesthouses, and bedrooms	30	During sleep
	Restaurant in the rest area	35	During meals
Commercial buildings	Large office	35	During work
	Meeting halls	35	During work
	Private office (applied)	50	During work
	Work centers, shops, etc.	60	During work
	Lunchrooms	45	During work
State Offices	Offices	45	During work
	Meeting halls	35	During work
Housing Areas	Bedrooms (in the city)	40	During night
	Living rooms (in the city)	55	Day through evening
	Service areas (kitchen) (inner-city, upstate, and city limits)	60	During activity

Source: Wetzel et al.1999.

Conclusions

The problem of noise is becoming a growing problem in big cities every day. This problem was determined especially at the Nalcaci Street in Konya city center as a result of noise measurements performed at morning, noon, and evening hours. Motor vehicles especially stop and get up at roundabouts, stopping to get passengers on the road, and sounding horns are the main reasons that increase the level of noise on the route.

Figure 7. Average Chart of Measurements Made at Morning, Noon, and Evening Time of All Measurement Points



When general averages of the values measured at measurement stations in the morning, noon, and evening were taken and shown on graphics, it was understood that there is a decrease in noise levels from the southern part of Nalcaci Street towards the north, which is from point 1 towards point 14 (Figure 7). Among all the measurement points, the lowest measurement was at point 14 at noon with 64.1 dBA, and the highest measurement was at point 2 with 80.8 dBA. The reason for the decrease in intensity towards point 14 is the underground passage, which a lot of vehicles go through.

All measurement points on the street were compared to the acceptable noise levels given in the regulation, assuming that the building gaps, such as windows and doors in the building envelope, are open. The values measured in all of the measurement stations were determined to be exceeding the limit values given in the Noise Control Regulation by 10–15 dBA. This result has negative effects on the health of the people affected by this noise in the environment and affects the indoor welfare and comfort in a negative direction. Such noise levels necessitate certain precautions.

Suggestions

It is a requirement that can be accepted by all, to reduce noise to acceptable levels, which noise causes human environments to lose their silence, threatens human health, and produces results that cannot be cured and treated. There are some precautions to decrease noise. These are:

1- Precautions for vehicles

1a- Vehicle speed factor: Reducing the speed of the vehicles both reduces the noise level and provides noise safety.

1b- Vehicle maintenance factor: Reparation and maintenance work on motor vehicles, especially checks on exhaust pipes, should be performed at regular intervals and specialists and use of punctured exhaust pipes must be banned.

1c- Vehicle driver factor: Collective taxis should be prevented from sounding horns unnecessarily.

1d- Road sensitivity factor: Heavy vehicles should be removed from noise-sensitive areas and alternative roads should be constructed.

2- Road precautions

2a- Road speed breaker factor: It is suggested to remove and reduce the number of speed breakers on the roads since they increase noise.

2b- Road quality factor: It is suggested to manufacture road coating materials using a less rough substance, which will also absorb sounds and minimize reflection.

3- Building precautions

3a- Source-building distance factor: The distance between a noise source and building should be increased.

3b- Building front design factor: Building fronts facing noise sources should be made as short and deaf as possible.

3c- Front sound breaker factor: There should be no protrusions, balconies, etc. on the front that faces a noise source.

3d- Environment-front factor: Openings in silent environments should be as small as possible.

3e- Mass reverberation effect: The masses must be designed to prevent noise from reflecting and increasing.

3f- Importance rating for isolation precautions: In our country, sound isolation is not paid attention to as much as heat isolation. In the buildings exposed to the noise on the street, it is necessary to apply double glazing with noise insulation materials especially on the fronts facing the noise source. However, since the sound insulation materials used in the walls are costly in terms of economy, more economically appropriate measures should be taken.

3g- Building envelope design factor: Sound insulation should also be added in the production of materials used for exterior walls and heat insulation, and designs should be made to create common solutions. The noisy interior performance of the building envelope, that is, the exterior building elements, is directly related to the external noise level. Therefore, the sound insulation values of the building envelope vary depending on the occupancy - space ratio of the envelope.

However, it is not possible to perform such a comprehensive evaluation. For this reason, the outer walls with the greatest total surface area in the building envelope are taken into account since they provide a large amount of sound insulation. Sound isolation values for a wall depending on its specifications. To determine the sound insulation value of the building element, generally, the calculation methods are used considering the superficial mass of the material. However, there are numerous examples of wall types that make up a building's envelope. To limit these, we have selected the wall types which are characterized and used widely in the standards produced in our single-layered and double-layered countries which are evaluated only by considering the surface masses. Table 9 gives a comparison of single-layer wall values measured for loss of sound transit (Kurra 2009).

Table 9. *A Comparison of Single-Layer Wall Values Measured for Loss of Sound Transit*

Material	Dimensions (cm)	Wall thickness (exc. plaster) (cm)	Sound Transit Loss (dB)
Masonry with horizontal openings	19x13.5x19	19	47
Masonry with vertical openings	19x19x13.5	19	49
Filled briquette wall	20x13.5x39	20	47
Pumice concrete block	19x39x19	19	47
Gas concrete block wall	60x20x25	20	46
Concrete wall	-	20	51
Double Wall Envelope	19x19x13.5	26	49
Building Envelope with Curtain Wall	19x19x13.5	27	52

Interior environment noise limit values in Nalcaci Street are given in Table 10, which is based on the 87.7 dB value that is the highest noise level acquired in the measurements performed at 14 points.

$$\Delta_{\max} = 87.7 \text{ dB}$$

Table 10. *Comparison of Single-Layer Wall Values, Compared for Sound Transit Loss, based on Noise Levels at Measurement Points*

		Masonry with horizontal openings (47 dB)	Concrete wall (51 dB)	Cellular Gas concrete wall (46 dB)	Double Wall Envelope	Building Envelope with Curtain Wall
		$\Delta_{\max} - \Delta_{\text{brick}} = 87.7 \text{ dB} - 47 \text{ dB} = 40.7 \text{ dB}$	$\Delta_{\max} - \Delta_{\text{concrete}} = 87.7 \text{ dB} - 51 \text{ dB} = 36.7 \text{ dB}$	$\Delta_{\max} - \Delta_{\text{cellular concrete}} = 87.7 \text{ dB} - 46 \text{ dB} = 41.7 \text{ dB}$	$\Delta_{\max} - \Delta_{\text{brick}} = 87.7 \text{ dB} - 49 \text{ dB} = 38.7 \text{ dB}$	$\Delta_{\max} - \Delta_{\text{curtain wall}} = 87.7 \text{ dB} - 52 \text{ dB} = 34.7 \text{ dB}$
Places	Interior noise level limit values					
Hotel	30	-10.7	-6.7	-11.7	-8.7	-4.7
Dormitory	30	-10.7	-6.7	-11.7	-8.7	-4.7
School	35	-5.7	-1.7	-6.7	-3.7	+1.3
Hospital	35	-5.7	-1.7	-6.7	-3.7	+1.3

Office	35	-5.7	-1.7	-6.7	-3.7	+1.3
Residential (Bedroom)	40	0.7	+3.3	-1.7	+1.3	+5.3
Residential (Living Room)	55	+14.3	+18.3	+13.7	+16.3	+20.3
Shop	60	20.7	+23.3	+18.7	+21.3	+25.3

3h- In the schools, hospitals, and office buildings with sensitive usage areas, the isolation of the windows should be done very well and the effect of external noise should be minimized and the application of double glazing should be increased.

Measures to be Taken Close to the Study Area

4a- Artificial barriers applied to reduce noise on highways and roads outside the city center are not recommended because there is not enough application area in the city and it does not appear aesthetic.

4b- Natural barrier application instead of artificial barrier application is the most suitable noise reduction measure for Nalcaci Street. Better results can be obtained if the herbal materials to be used in noise prevention are selected from a variety of common, broad-leaved, thick, and feathered leaves. Thus, there is a chance that the plants can suppress noise to a certain level. In road tree planting studies, the selected plants which are suitable for the purpose must be connected to the environment with their aesthetic and physiological characteristics.

Leaf-bearing plants should have short leaf-bearing periods and they should remain green and fruitful in all seasons. In the selection of species, consideration should be given to the relationship among road class, the use of the surrounding area, plant-road, structure and infrastructure, and the selected species should be suitable for road and environmental structures. Planting is not only effective in reducing noise, it also reduces the effects of sun and rain on the drivers, as it reduces dust generated during navigation. Not only roadsides but also refuges should be planted. Because planting can both serve human beings functionally and aesthetically. Approximate sound minimization values are given in the Hungarian Traffic Noise Prediction Model, based on various tree types. Shrubbery group provides the most effective noise suppression. This suppression is observed as between 9–10 dBA at 60 meters (Beranek 1974).

Pinewood: 0.1–0.15 dBA/m (1–1.5 dBA reduction at 10 meters)

Broad-leaved trees: 0.08–0.1 dBA/m (0.8–1 dBA reduction at 10 meters)

Shrubbery: 0.15–0.17 dBA/m (1.5–1.7 dBA reduction at 10 meters)

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