Stacy Sachdev (HES ID: 00685634)
Harvard ENVR E-599 Independent Research Capstone

# No pain, no gain? Benchmarking user-level risk in the gym environment during the 2020 pandemic cycle


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## Abstract

From September 2020 through November 2020, three hundred ninety-nine (399) pieces of gym equipment, across twelve (12) fitness facilities were studied within the Cypress, TX city limits to benchmark risk with respect to two dependent variables: i.) Personal-Space Intrusion at the ground-level, and ii.) Airflow at the face-level. Personal-Space Intrusion was algebraically calculated by measuring the intersect of six-foot diameter circular areas, center point-to-center point, for adjacent equipment (in all directions) on fitness floors. The six-foot spacing requirement is derived from the State of Texas (Governor's office) and Center for Disease Control (CDC) guidance on social distancing. The results, across and within gyms, reveal variance to the target (no personal space intrusion). Cardio zones for example experience a mean intrusion rate of 64% of personal space. Free Weight zones exhibit 19% mean intrusion, and Weight Machine zones exhibit 4.2% mean intrusion. For the sample, the results indicate that fitness floors are not currently setup to both maximize capacity (all equipment fully manned) and enable socially distant exercise. Targeting cardio setups to reduce intrusion is tactically appropriate.

For the face-level environment, airflow rates were measured with a digital anemometer across Cardio (12 gyms, 9,909 sq. ft.), Free Weight (11 gyms, 6,026 sq. ft.), and Weight Machine (10 gyms, 8,280 sq. ft.) zones. Environmental stability and capability were tested on transformed airflow data through a capability analysis. No target was provided for the analysis. Rather a lower and upper airflow boundary (0 ft/s and 3.645 ft/s) was utilized. The LSL and USL are borrowed from Dbouk, et al (2020) who conducted a study of respiratory droplet settling distance and period in controlled conditions at specific airflow measures. In 0 ft/s airflow, respiratory droplets traveled 3.28 ft in 49s (Dbouk, 2020). In 3.645 ft/s airflow, respiratory droplets traveled up to ~20 ft in 5s (Dbouk, 2020). The Xbar-R Chart as well as the Z-bench scores provided by the analysis indicate that airflow at the face-level, in fitness environments, measures between 0 ft/s to 3.645 ft/s across all zones and is capable of staying within that range, but is not stable across the gyms studied. This indicates that across fitness facilities, users can expect to be subject to varying airflow which may introduce both a level of comfort (cooling) as well as risk (extended respiratory droplet settling distances). More research is needed to develop an industry target on recommended airflow rates within these environments.

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# 1. Introduction: Benchmarking Risk in Fitness Facility Environments

## 1.1) The marketplace for brick and mortar fitness facilities is declining

From July 2017 through July 2019 the year-over-year (YoY) growth in share price for Planet Fitness (NYSE: PLNT) was approximately +14% ('16-'17), +102% ('17-'18), and +66% ('18-'19) respectively (Yahoo Financials, 2020). By comparison, the July 2020 YoY change for the company was -21%. Up and down swings in share price are not uncommon, however Planet Fitness represents a unique look into the Health & Fitness industry: they are large (~1300 clubs), inexpensive ($10/month option), and popular (~8.9MM members) (Smith, 2018). In addition, they are one of the few large fitness brands which are not privately held. This makes Planet Fitness a fair proxy for gauging the marketplace, which through 2016 had been outpacing the U.S. gross domestic product (GDP) by 1.4x (Smith, 2018). The gym industry however is no longer growing, and the pandemic environment in 2020 has resulted in a more risk-averse consumer, driven in-part by the virus causing coronavirus disease 2019 (COVID-19). Current scientific literature advises that COVID-19 is spread through transmission of respiratory droplets, with the additional possibility of suspended aerosol transmission (CDC, 2020) (Tellier, 2006) (Lu, 2020). The lack of a vaccine (until late-December 2020) for the disease is part of the consumer risk-aversion, which has led to membership attrition, and subsequently bankruptcy filings for traditional large big-box fitness brands such as 24Hour Fitness and Golds Gym (Pandise, 2020). Continued membership attrition in 2020 (and beyond) will not lead to the death of exercise, but it is certainly leading to the demise of brick and mortar fitness facilities. To this end, investigating the physical, current-state, gym environment is tactically important in answering the question: is it safe to return to the gym?

### 1.2) Good Health and Well-Being (United Nations Sustainable Goal #3) is imperative

The reduction in fitness facilities and the subsequent erosion of the "big gym culture" are important to note and to mitigate. The argument that fitness facilities can be replaced by at-home exercise is reasonable, however an industry report from IBISWorld reveals that the gym and exercise equipment manufacturing industry is only expected to grow roughly 1.25% annually through 2023 (Ristoff, 2020). This is not significant growth. Additionally, the individual consumer demand for exercise equipment is not the primary driver of revenues for gym equipment and manufacturing, which means that it is reasonable to assume that attrition in gym memberships may lead to a drop in overall exercise. This assumption is corroborated by a recent study which was published by the American College of Physicians (ACP) Annals of Internal Medicine. The study revealed that from January 1, 2020 to June 29, 2020, there were varying levels of decreased physical activity worldwide (measured in steps taken) ranging anywhere from ~5% to 27% decrease within the first 30 days of the pandemic declaration (with continuing measurements thereafter) (Tison et al, 2020). To this end, addressing the risk-aversion in fitness facilities may enable increased physical activity and by association "good health and well-being". This opportunity represents a social responsibility, and has particular relevance when investigating the positive role that physical activity has in improving depression (Cooney, et al, 2002), weight loss (Cox, 2017), social interaction (Onea, 2019), and general medicinal and physical therapy associations (ACSM, 2007; Yang et al, 2015). In addition, the Center for Disease Control (CDC) advises and references recent studies which correlate obesity with

COVID-19 outcomes. Increased risk of illness, hospitalization rates, and lower vaccine response are a few of the obesity themes reflected in the research (CDC, 2020a).

### 1.3) Is it safe to go back to the gym? The academic significance of the question.

Revenue and cost control are commonsense drivers for maintaining and growing a business. The attrition in gym memberships during the pandemic environment represents an average, pre-pandemic, revenue loss of nearly $442 annually per member (Smith, 2018). In order to bring fitness facilities back to pre-pandemic levels, members need to return. In order for members to return, fitness facilities need to mitigate respiratory droplet transmission of bacterial and viral occurrences (not just COVID-19) to ensure that they are providing a safe environment inclusive of local regulations, federal guidance (example: Center for Disease Control), and industry recommendations (example: American College of Sports Medicine). Benchmarking variables at the ground-floor level, face-level, and ceiling-level environments within fitness facilities is the objective of this study. Observations of the data are intended to help to identify gaps in operational readiness for fitness facilities that are currently open.

Previous academic and industry literature reveals that several variables have already been investigated. Dalman, et al (2019) investigated occurrences of *Staphylococcus (S.) aureus*, which is a common bacterium found in the nose and throat of individuals, by taking swabs within and across fitness facilities in Northeast Ohio. Occurrence rates of S. aureus were found across various types of equipment with weight balls, curl bars, weight plates, and treadmill handles representing higher rates (Dalman, 2019). Tellier (2006) investigated the transport patterns of Influenza A, and warns that the perception of large-droplet transmission of Influenza A (H5N1) may have led to less preparedness against aerosol transmission of the virus. This was corroborated by Lu (2020) who reports an occurrence of COVID-19 in a restaurant located in

Guangzhou, China which is believed to have traveled through the air-conditioning vents from one table to another. To this end, there seems to be a gap in literature with respect to ventilation audits within fitness facilities.

Additional academic and industry literature on physical hazards have also been investigated. Gray, et al (2014) performed an Australia-wide six-week national survey of fitness industry employees. The study revealed that most respondents (~80%) were satisfied with facility access, floor surfaces, lighting etc. (Gray et al, 2014). Sekendiz (2018) highlights the gray-area of fitness facility waiver forms as a basis for defense against claims of physical harm or injury that occurs to users of these facilities. Cruz (2020) spotlights the gap in safety consulting services for gyms, indirectly, by showing that a large segment of the customer-base for these services is often manufacturing facilities, process environments or offices, not gyms. As such, given the current pandemic setting, there seems to be a gap in research with respect to social distancing and ground-level equipment layouts in fitness facilities.

### 1.4) Research internalizations and externalizations

Addressing the current gaps with respect to ventilation audits and socially distanced equipment layouts in fitness facilities were the primary variables of study. Eight (8) residential gyms (i.e. apartment complex/homeowner association (HOA) funded facilities), three (3) 'mid-size' chain-gyms (Snap Fitness, Orange Theory) and one (1) big-box gym (Planet Fitness) within Cypress, TX were part of the study. These gyms represent 399 data-points (pieces of equipment across cardio, free weight, and weight machine zones). Cypress, TX itself (median age: 32, median income: $109,000) was the geographical boundary for the study due to accessibility and demographic alignment with the largest proportion of pre-pandemic gym members (ages 25-34: 36% of the gym population, income $100,000-$199,000: 35%) (Smith, 2018) (Census Reporter, 2018). The physical boundary (within fitness facilities) were the ground-level and face-level environments. The atmospheric environment was excluded from the study due to lack of accessibility to the Heating, Ventilation, and Air Conditioning (HVAC) roof-top units and ceiling-level ducting. Cardio, free weight, and weight machine areas were included in the study. All other areas, such as locker rooms, group fitness open-areas, and front-desk/reception were excluded. Variables that have previously been covered by academic research (referenced herein) were also excluded. The number of gym patrons is not fixed and is likely based on individual preferences relative to time and exercise goals, therefore for the purposes of the study, all pieces of free-standing equipment (including benches) were always assumed to be manned by a single user.

### 1.5) The research hypothesis

For the ground-level environment the primary variable was equipment-layouts and spacing. The CDC currently advises six (6) feet of personal space (CDC, 2020). Recent research on aerosol transmission of respiratory droplets provides an argument that 6-feet of personal space may not be enough (Dbouk, 2020). This is noted; however, the CDC guidance is leveraged as a minimum target for this research. Between two individuals this can be represented by the non-intersection of two circular 3-foot radii, with each individual owning 3-feet of personal space in a half-arc, in addition to, another 3-feet of personal space in the other half-arc (radiating from the center-point of an individual). This equates to a total diameter of 6-feet per person with a personal-space area of 28.26 square feet (sq. ft.). Intrusion of this personal-space area was calculated and statistically compared to the target (zero sq. ft. of personal-space intrusion). Details are highlighted in Section 2 below. To this end, the research takes an "innocent unless proven guilty" approach. The null hypothesis ($H_{n\text{-ground}}$) is that the difference between the response (average of personal-space intrusion normalized as a percentage within specific zones) and the target is not statistically significant. The alternative hypothesis ($H_{a\text{-ground}}$) is statistical significance.

For the face-level environment, the primary variable is airflow (measured as feet per second) (ft./s). Among other guidelines, Texas ventilation code recommends that fitness facilities maintain a benchmark volumetric flow rate of 20 cubic feet per minute (CFM) per person in the gym (IMC, 2015). This can be measured with an anemometer at the air-return and air-supply vents, however the atmospheric-level environment (ceiling-level) is externalized from this research due to accessibility issues. To this extent, the CFM requirement may still correlate with the face-level (breathing) environment by measuring airflow. Airflow is important for ensuring that "air moves from clean to dirty and out" (NAU, n.d.). For the purpose of this research, dirty air is defined by the interaction of respiratory droplets (from coughing or sneezing), airflow rates, and the settling-distance of the cloud-particles. The null hypothesis ($H_{n\text{-face}}$) is that the dependent variable (airflow rate within specific zones measured by a digital anemometer) is representative of a stable and capable environment, meaning that the airflow measurements, across and within gyms, falls within the lower specification limit (LSL) and upper specification limit (USL) of 0 ft/s and 3.645 ft/s. The LSL and USL rely upon Dbouk's (2020) work showing that, at 68-degrees Fahrenheit, 50% relative humidity, and 1 atm, respiratory droplets can travel anywhere from 3.28 ft (in 0 ft/s air flow with a 49 second residence time) to 19.68 ft (in 3.645 ft/s airflow with a 5 second residence time). The alternative hypothesis ($H_{a\text{-face}}$) is statistical significance (an environment that is not stable and/or capable of staying within the LSL and USL).

# 2. The Research Methodology

## 2.1) Ground-level environment approach

Areal intrusion into personal-space ($ft^2$) was measured from ground-level, with equipment-to-equipment distances in cardio, free weight, and weight machine zones across fitness facilities. Assessing this primary response variable involved four primary collection methods: i. Harris County Engineering Building Submittals, ii. Photographs, iii. Virtual tours, and iv. Physical on-site surveys. Geometric modeling of the physical separation of equipment is overlaid with a 6-foot diameter circular personal-space area for each piece of equipment. The approach calculates the physical area of intersect between circular personal-space zones. Measurements are recorded and tested for process capability by zone (cardio/free weight/weight machine). The process capability itself maps the response against industry-defined upper and lower specification limits for allowable intrusion. The capability target follows the CDC minimum spacing recommendation, which also aligns with State of Texas guidance (no personal-space intrusion recommended). The measurements represent continuous data; thus, the process capability encompasses tests for: a) normality, b) process stability, and c) process capability. P-values and Z-bench values are used to benchmark the fitness environment at the ground-floor with respect to equipment layouts. Rejection, or a fail-to-reject, decision for the null hypothesis is guided by the P-value and Z-bench outcome. Table 1 highlights various industry and government sources along with their guidance values. The process capability test utilizes an upper specification limit (USL) (max allowable intrusion) of 0.714 sq. ft. along with a lower specification limit (LSL) (recommended intrusion) of 0 sq. ft. The USL complies with guidance provided by the American College of Sports Medicine (ACSM, 2012). While the LSL (which also serves as the target) is specified by the State of Texas (in alignment with the CDC) (Texas.gov, 2020). To evaluate the response, secondary tests against multiple independent variables are also examined to identify sources of variation. These multiple independent variables include zone volume (ft3), zone area (ft2), gym type, and equipment type.

**Table 1**: Ground-level USL, LSL, and Capability Target Referenced from Industry Sources

| Industry/Government Sources | Area (Sq. Ft.) | Radius (Ft.) | Intrusion allowable (positive values) (Sq. Ft.) | Intrusion Spec Limit Description |
|---|---|---|---|---|
| ACSM Equipment space minimum (Sq. Ft.) (ACSM, 2012) | 20.000 | 2.523 | 0.714 | Max Intrusion Allowed (USL) |
| ACSM Equipment space max (Sq. Ft.) (ACSM, 2012) | 40.000 | 3.568 | -1.014 | Equipment separation Recommended |
| CDC Recommended Distancing (CDC, 2020) | 28.274 | 3 | 0.00 | Target (No Intrusion) |
| Governor's Office, State of Texas (social distancing) | 28.274 | 3 | 0.00 | Recommended Target (and LSL) |
| Department of Health, State of Minnesota (MDH, 2020) | 28.274 | 3 | 0.00 | Minimum Target (No Intrusion) |
| United Kingdom Department of Business (UK DoB, 2020) | 100 | 5.642 | -21.927 | Target Spacing Recommendation for Usable Equipment |

## 2.2) Face-level environment approach

Airflow (ft/s) measurements for the face-level environment was tested utilizing the hypothetico-deductive approach across the study zones. These measurements were taken both standing and walking at face-level (5 foot, 9 inches off the ground), utilizing a Proster MS6252A digital anemometer with a sensitivity rating of 0.01 ft/s, +/- 2%. As mentioned in Section 1.5, Dbouk's (2020) study was leveraged for the LSL and USL boundaries to test for environmental capability and stability. Reject, or fail-to-reject, decisions for the null hypothesis are guided by the response P-value and Z-bench outcome. To this end, the $H_{n\text{-}face}$ was stable and capable airflow, while the $H_{a\text{-}face}$ was non-stable/non-capable airflow.

Secondary calculations benchmarked Air Changes per Hour (ACH) within fitness facilities through actual area calculations. These are mapped against the upper (12 ACH) and lower (8 ACH) boundaries recommended for fitness facilities by the American College of Sports Medicine (ACSM, 2012). The ACH calculation serves as an observational basis for addressing whether industry standards need to be updated, albeit without considering atmospheric-level (ceiling-level) measurements (externalized here). Texas ventilation code for example recommends 20 cubic feet per min (CFM) per person within fitness areas. The volumetric size of the specific zone, number of fans, number of vents, and number of equipment delineate different ACH minimums. Mapping these minimums against ACSM guidance may reveal gaps (across gyms in the study) between advised and required ACH.

*Air Changes per Hour (ACH) =*
*[(CFM per person) x (60 minutes/hour) x (number of equipment pieces within a zone)] divided by (volume of a zone, cubic feet).*

*(Premises: each piece of equipment represents a single user, always manned, to model a gym at full capacity).*

**Table 2**: Air-Changes per Hour (ACH) recommended vs. required

| Industry/Government Sources | ACH-Lower Limit for Fitness Environments | ACH-Upper Limits for Fitness Environments |
|---|---:|---:|
| American College of Sports Medicine (recommended) | 8 | 12 |
| Texas Ventilation Code (required) | 20 CFM per Person (calculation dependent ACH) | 20 CFM per Person (calculation dependent ACH) |

### 2.3) The variables and hypothesis-testing

Table 3 highlights all the variables collected in the study including some which are tertiary to facilitate future initiatives that either build-on or audit this research. The physical boundary of the study (Cypress, TX) requires that any future repeatability or reproducibility (gauge R&R) studies, within city limits, have this tertiary information in order to identify potential sources for variation up-front. Example: a gym increases or decreases its physical footprint over time, changes its classification (big-box, high-value, etc.) or even goes out of business. Primary and secondary response variables are also identified. These are tested using Minitab v.19.

**Table 3**: Variable Description, Categorization, and Collection

| Variable | Description | Continuous/ Discrete | Environment-level | Variable-level | Collection Method |
|---|---|---|---|---|---|
| GymName | Name of the gym | Discrete | ALL | Tertiary | Online/Harris County Engineering Building Submittals |
| GymLAT and GymLONG | Latitude and Longitudinal coordinates | Continuous | ALL | Tertiary | Online/Harris County Engineering Building Submittals |
| GymType | Residential/Big-Box/High-Value/Boutique | Discrete | ALL | Secondary (Independent-X) | Industry guidance (Smith, 2018) |
| GymOpen and GymClose | Facility operating time (2400 standard hours) | Continuous | ALL | Tertiary | Gym website |
| Airflow | Zone-specific average airflow (ft/s) | Continuous | Face-level | Primary (Dependent-Y) | On-premise measurements (Proster MS6252A) |
| Volume | Zone-specific Area multiplied by zone-specific ceiling height ($ft^3$) | Continuous | ALL | Secondary (Independent-X) | On-premise measurement/Harris County Engineering Building Submittals/ Virtual measurement (i.e. Matterport software) |
| Equipment COUNT | Zone-specific count of equipment | Discrete | Ground-level | Secondary (Independent-X) | On-premise measurements/Harris County Engineering Building Submittals/Virtual counts (i.e. Matterport software) |
| DEEP_RED | Total incremental intrusion of personal space (ft^2) within each zone | Continuous | Ground-level | Primary (Dependent-Y) | Calculated |
| DEEP_RED_AVG | Average intrusion of personal space (ft^2) within each zone | Continuous | Ground-level | Primary (Dependent Secondary-Y) | Calculated |
| DEEP RED AVG(%) | Average intrusion of personal space (ft^2) within each zone normalized over all data points as a percentage (%) | Continuous | Ground-level | Primary (Dependent Secondary-Y) | Calculated |
| CalculatedACH | Gym-specific, zone specific calculated air change per hour (ACH) rate to meet a 20 CFM per person requirement | Continuous (rounded-up to the nearest whole number) | Face-level/Atmospheric-level | Primary (Dependent Secondary-Y) | Calculation |

The statistical methodology for hypothesis testing follows General Electric protocols (GE, 2013) and is validated using Johnson (2004).

**First**: to inform which statistical models are implemented, the primary response variables for both ground-level environment (personal-space intrusion) and face-level environment (airflow) are tested independently for normality. [1]

**Second**: after testing for normality, the primary response variables are tested for process (environmental) stability. This is performed by utilizing an appropriate control chart. The control chart maps individual data points as well as the movement calculated between data points. An environment that is stable does not necessarily mean it is capable. The reverse may also be true. Minitab detects this by mapping the data points against a process-generated upper and lower specification limit. Therefore, the actual measurements determine the capability USL and LSL.

**Third**: after testing for process stability, a test is performed for process capability. This is the primary test to be leveraged in either rejecting, or failing-to-reject, the null hypothesis established for ground-level and face-level studies. The data points are mapped against three attributes: industry defined USL, LSL, and capability targets. A probability-value (P-value) less than or equal to 0.05 is the threshold for deciding on the null hypothesis. Null hypothesis rejection triggers a study of the variation source (X's) (as described in the first step). In addition to the P-value, the Z-bench score will be referenced to determine process (environmental) sigma

[1] Normality is important to test, because in a Y = f(X) model the testing of discrete inputs (X's) (with a continuous Y-variable) requires an understanding of both variation and centering among the total study-population of data-points. If data are normally distributed, then a Bartlett's Homogeneity of Variance (HOV) or F-test HOV is performed to understand variation. If data aren't normally distributed, then a Levene's HOV test is performed. Similarly, for centering, a 1-Sample T-test, 2-Sample T-test, or One-way Analysis of variance (ANOVA) is utilized for normal data. A 1-Sample Sign Test, Mann Whitney test, or Mood's Median test is leveraged to test centering for non-normal data.

level. An environment that is highly capable will return a Z-bench value approaching four (4) to six (6) which represents the ideal-state. Figure 1 and Figure 2 are *examples* of stability and capability analysis that are leveraged for this research.

**Figure 1**: *Representative* fitness-environment stability and normality test

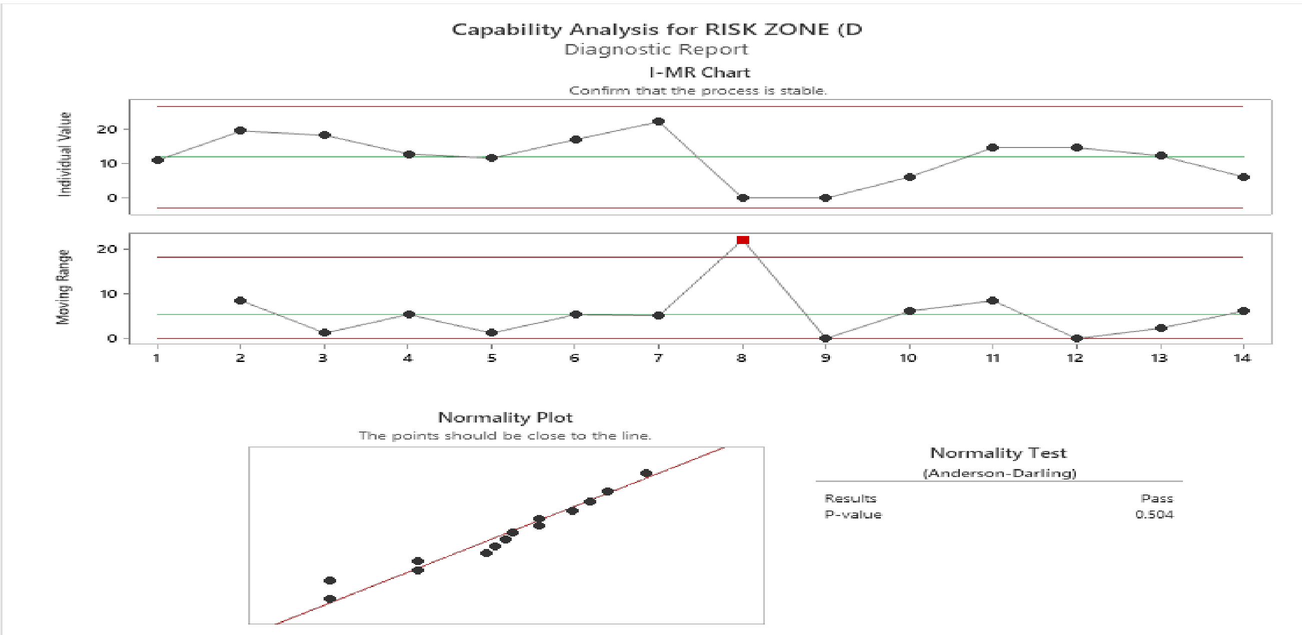
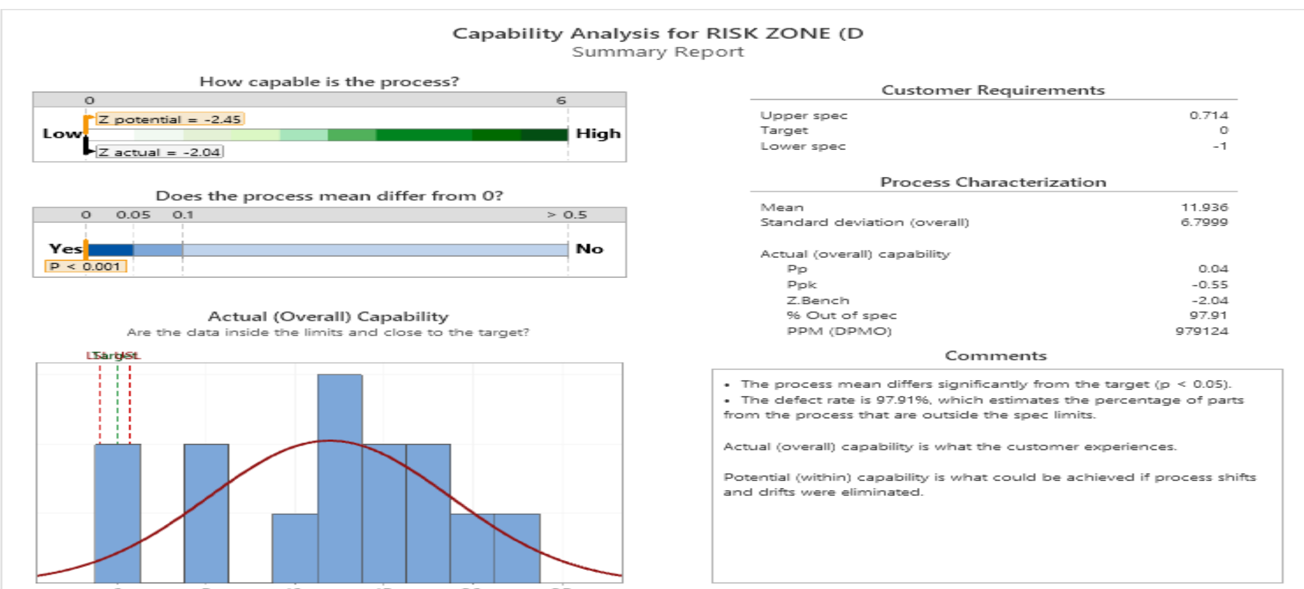



**Figure 2**: *Representative* fitness-environment capability analysis report



## 3. Results & Discussion

### 3.1) Intrusion of personal space in gym setups is an issue

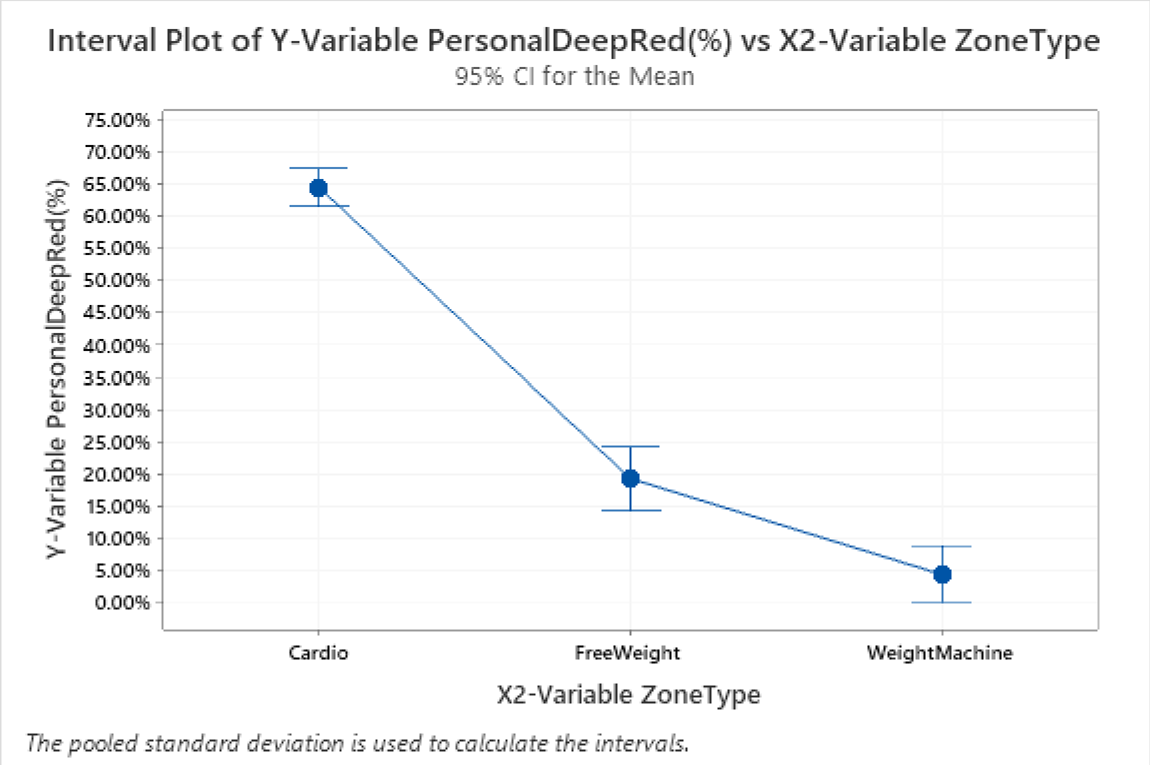
Analyzing potential personal-space intrusion at the ground (floor) level of fitness facilities entailed 221 pieces of cardio equipment, 81 pieces of free weight equipment, and 97 pieces of weight machine equipment. Personal experience utilizing these facilities led to a biased view that the environment (equipment layout) was not stable or capable of meeting the minimum social distance requirements. This bias proved to be reasonably true. The average personal-space intrusion across all three zones in the study had a statistically significant difference when compared to the target (0 square feet of personal-space intrusion). Table 4 below highlights the representative P-values and Z-bench scores produced from the capability analysis (please see Appendix for Minitab outputs). The Z-bench scores are important to note, because environments that exhibit "world-class" levels of stability and capability typically approach a Z-bench score of 4 to 6 (this aligns to the sigma level of a process) (GE, 2013).

**Table 4**: Capability analysis results for cardio, free weight, and weight machine zones

| Zone | Mean personal space intrusion in sq. ft. | Target intrusion (sq. ft) | P-value | Z-bench score (actual) |
|---|---|---|---|---|
| Cardio | 18.22 (64%) | 0.1 (0%) | <0.001 | -2.88 |
| Free Weight | 5.449 (19%) | 0.1 (0%) | <0.001 | -1.90 |
| Weight Machine | 1.201 (4.2%) | 0.1 (0%) | <0.001 | -1.27 |

No zone within the study exhibited ground-level stability or process capability, therefore the null hypothesis is rejected. In other words, fitness environments are statistically poor in setting up equipment to enable compliance with the State of Texas (and CDC) social distancing recommendations. In addition, within each gym and each respective zone (cardio/free weight/weight machine) considerable variance exists in the amount of intrusion that a single user can experience (highlighted in Figure 3; assumes constant deployment of each equipment piece, singly, by users). In November 2019, the gym industry was not operating in a “commercially known” pandemic environment. Seemingly overnight, that status ended due to risk-aversion of COVID-19. Reconfiguring the gym environment to enable social distancing represents one of several opportunities to operate a safe, fully occupied capacity within these environments. Accordingly, the results provide some interesting insights. Cardio environments for example exhibit the highest levels of mean-intrusion (64%), however free weight zones (19%), and weight machine zones (4.2%) have much less personal-space intrusion (in other the words, the equipment is more widely dispersed). There are even multiple data points (83 total) within free weight and weight machine zones that exhibit no personal-space intrusion. Thus, it is indeed possible to go to a fitness facility and find areas where you can perform resistance training while also being socially distant (even if there are adjacent free weight benches or weight machines manned around you). The same is not true for cardio equipment. No cardio data points (pieces of adjacent equipment) exhibited zero (or near zero) personal-space intrusion. Some gyms are limiting capacity and/or limiting which equipment can be utilized. This method represents a good, commonsense approach to achieving some-level of distancing. It is, however not a “bullet-proof” strategy. Indeed, the data obtained here indicate that, in some instances (22 data points, Planet Fitness), there are abnormally high levels of intrusion (over 95% of personal space). For these occurrences, the proximity of adjacent cardio equipment is so close that there is a double overlap of personal-space intrusion. Pandemic gym policies should consider phased timing for use of equipment. A gym user could for example, log into a mobile application and reserve a specific timeslot for their exercise.

**Figure 3**: Analysis of Variance output (P-value = 0.000) (source: Minitab)

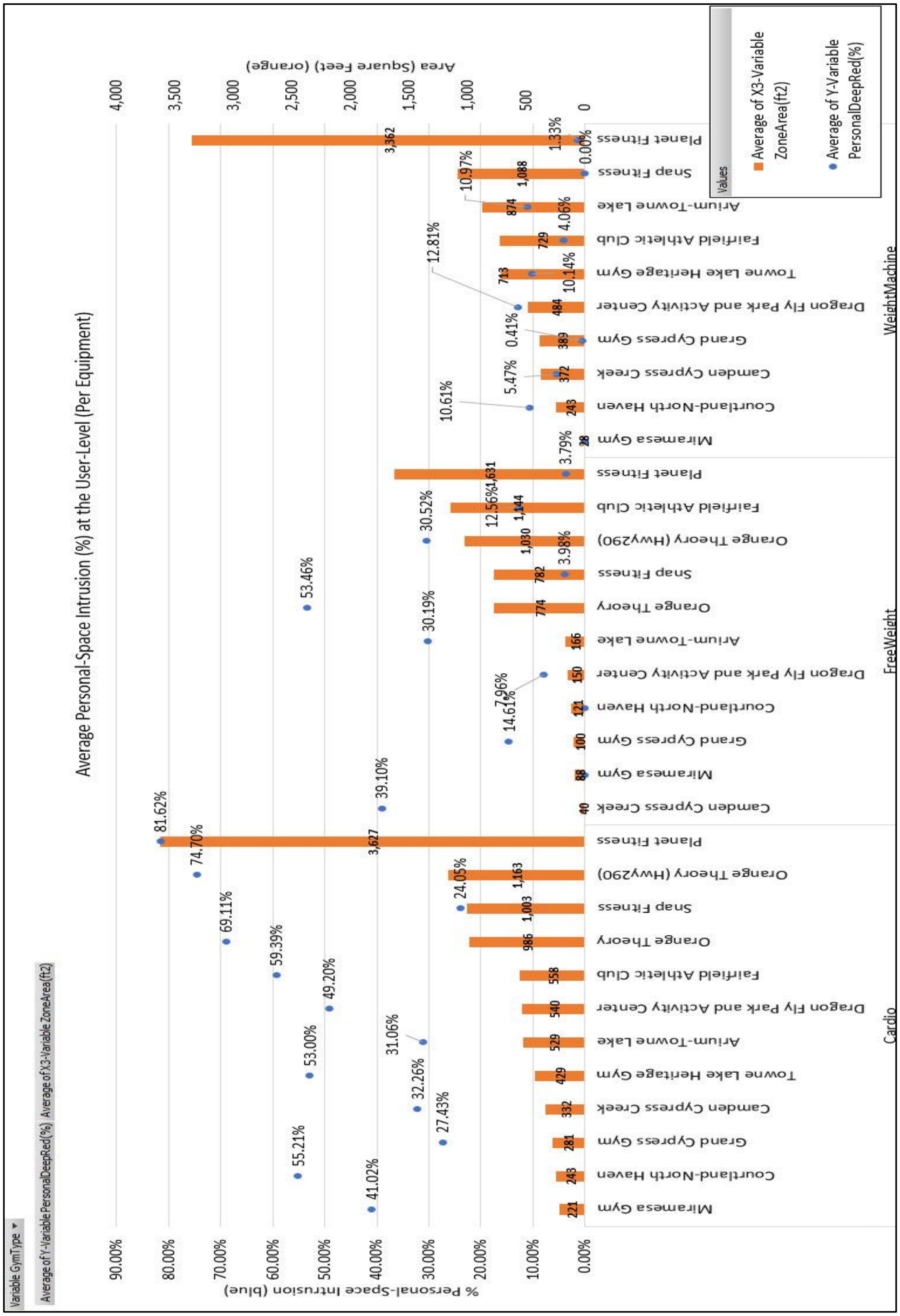



### 3.2) Other independent, ground-level, variable interactions with Personal-Space Intrusion

**3.2.1.** Personal-space intrusion as a function of area

It is natural to assume that smaller spaces will require greater levels of care with respect to the total number of available equipment pieces that can be safely arranged. Interestingly, however, graphical analysis does not show a strong trend between Area and mean Personal-Space Intrusion (Figure 4). Since the comparison is made at the aggregate-level, the overall number of data-points is low. More fitness facilities will need to be included in future studies to get a better representation of interaction.

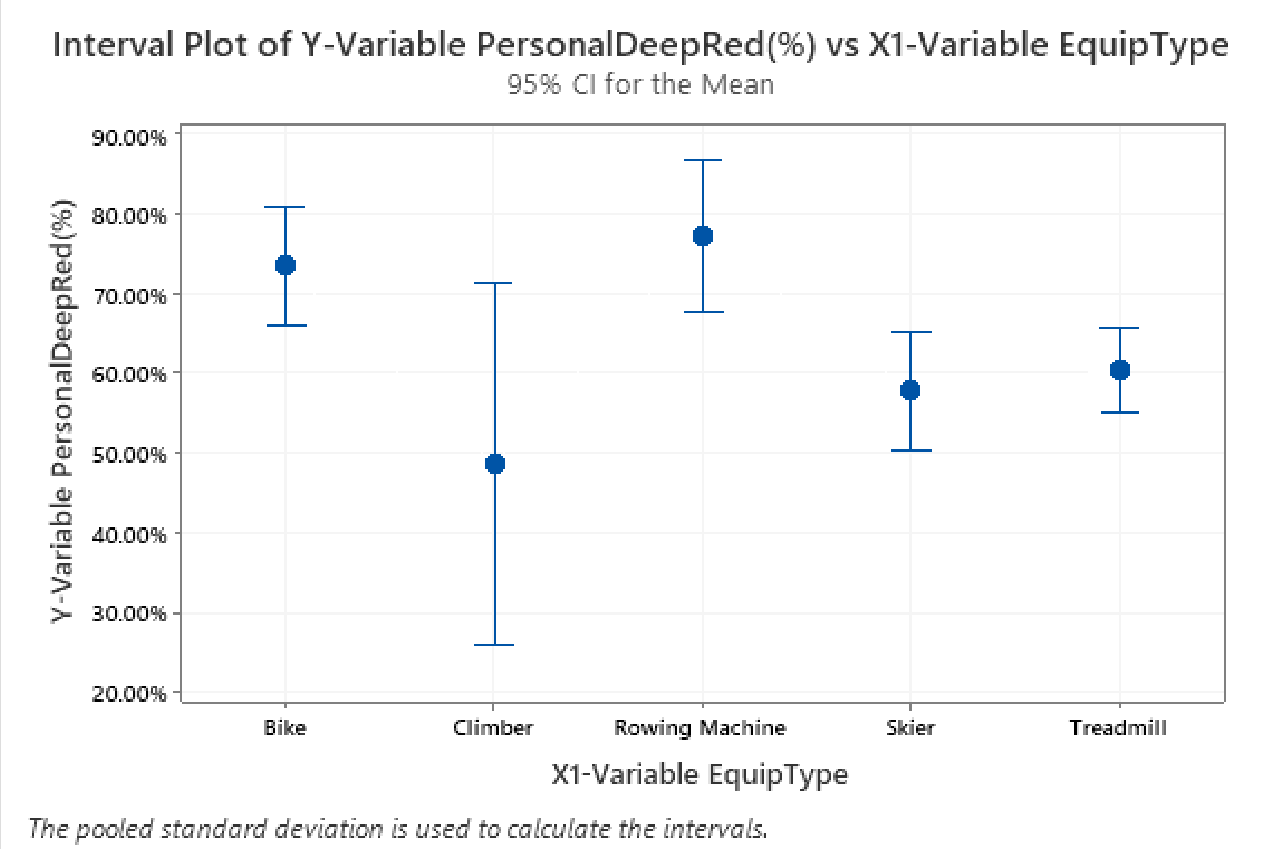
**Figure 4**: Average personal-space intrusion (%) by fitness facility by zone-type



### 3.2.2. Personal-Space Intrusion as a function of Equipment-Type

There are statistically significant differences between variances (of personal-space intrusion rates) exhibited by equipment within all three zones. Since the data are non-normal, a Homogeneity of Variance (HOV) Levene's test is performed for each zone. For cardio zones: 97 Treadmills, 47 Stationary Bikes, 46 Skiers, 29 Rowing Machines, and 5 Climbers are analyzed. The Levene's P-value is 0.012, which indicates that variances differ substantially among the cardio equipment. For free weight zones: 46 Benches, 14 TRX Systems, 8 Abs Benches, 5 Smith Machines, 4 Chest Press Benches, 2 Arm (curl) Benches, 1 Lower Back Bench, and 1 "Cable-Type" Machine are analyzed. The low number of data-points among some of the free weight equipment influenced the Levene's P-Value (0.145) however the Multiple Comparison test (P-value = 0.000) indicates some level of statistically differing variances among the equipment. Finally, for weight machine zones: 34 Leg Machines, 12 Back Machines, 12 Chest Press/Fly Machines, 11 Shoulder Presses, 8 Arm Machines, 7 Multi-System Weight Machines, 4 Abs Machines, 3 Smith Machines, 2 Press Machines, 2 Weighted Benches, and 2 Cable/Rope Machines are analyzed. The Levene's P-value is 0.004, which indicates that variances among weight machines differs significantly. The output tables for these tests can be found in the Appendix. Figure 3 below highlights the graphical output performed by a 1-Way ANOVA test for each zone. ANOVA tests assume normality, but the Kruskal-Wallis test can handle non-normal data (GMU, n/d). For the purposes of presenting statistical significance, the Levene's test is leveraged. The graphical output of the 1-Way ANOVA, however, is a representation of performance equipment-to-equipment within these zones. The ANOVA output tables can be found in the Appendix.

**Figure 5**: 1-Way ANOVA plot of Cardio-zone mean Personal-Space Intrusion (%)
(free weight zone and weight machine zone plots in Appendix)



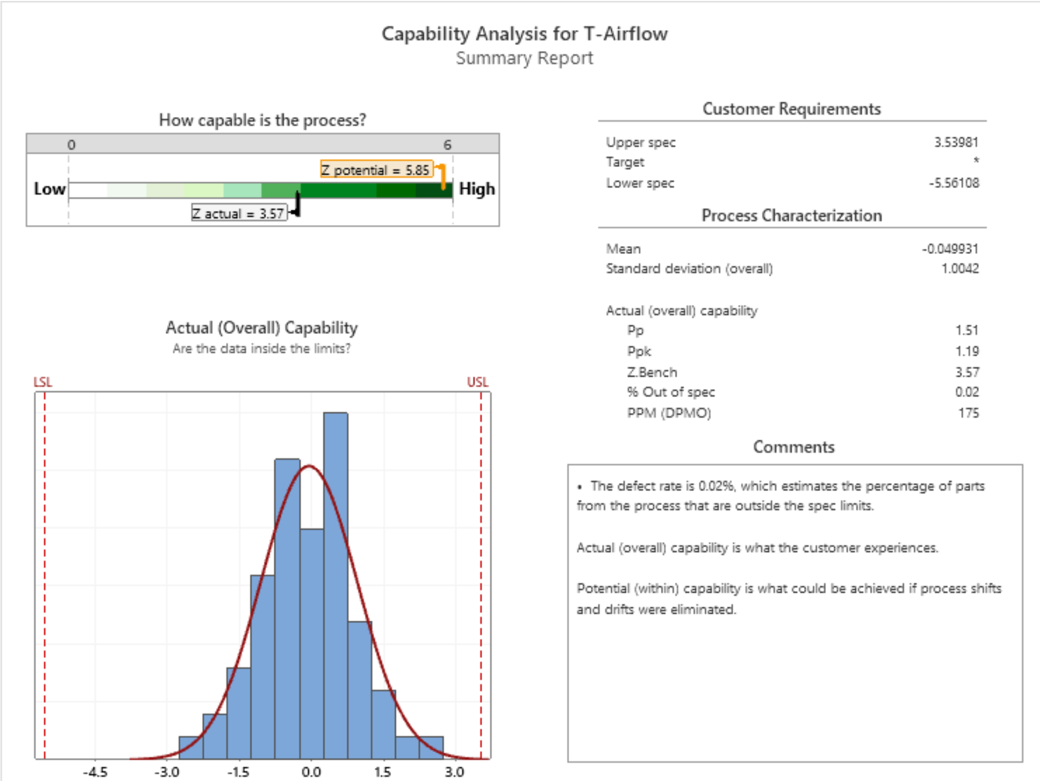

### 3.3) Airflow rates within gyms are not stable, but are predictable and capable

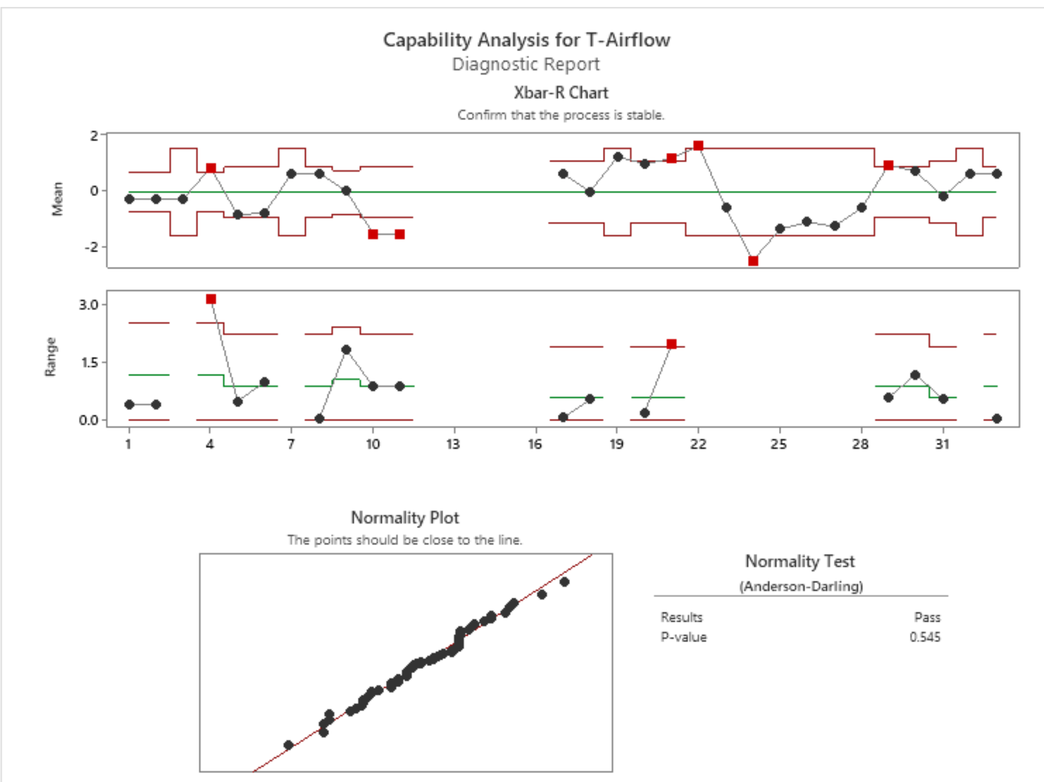
Seventy-seven (77) total airflow measurements were taken from September 2020 through November 2020 across twelve (12) different fitness facilities within Cypress, TX (see Appendix for data table). Individual measurements (as opposed to mean airflow by area) are utilized for statistical testing to incorporate the influence of variance arising due to non-measured variables interacting with the Proster MS6252A anemometer (i.e. walking speed, wind-zones from variable arrangements in equipment [think: virtual corridors], the influence of cross-flow from other individuals walking on the fitness floor, etc.). Future repeatability and reproducibility exercises to validate the specific measurements is likely to be difficult due to the varying nature of the external variables present in fitness environment (at any moment in time). However, taking the measurements and normalizing both the current (this research) and new (future research) datasets may allow for a graphical analysis to be performed, in which dispersion around the mean can be measured and compared between this study and a future study to re-gauge airflow stability and capability. As a reminder, airflow rate is the primary response measured for the face-level (breathing) environment, because the measurements and analysis are intended to build-off (and compliment) the study performed by Dbouk, et al (2020) – in which respiratory droplets were measured for settling distance, resonance, and time in varying airflow within a controlled environment. The humidity (50%), temperature (68$^{o}$ F), and pressure (1 atm) of the controlled environment within Dbouk's study line-up with the recommended conditions set forth by the American College of Sports Medicine (68$^{o}$ to 72$^{o}$ F, humidity levels at 60% or less) (ACSM, 2012). In addition, the LSL (0 ft/s) and the USL (3.645ft/s) are borrowed from the Dbouk study since these values have a specific measured settling distance over time (Dbouk, 2020). The settling distance is not correlated to any of the airflow measurements taken within this research, since each fitness facility in the study will have its own unique environment. The "uniqueness" of each environment is anticipated to introduce variation against the controlled conditions set forth by Dbouk. Thus, in order to avoid error in comparison (and subsequently judgement) the hypothesis at the face-level is tested only for "current-state" stability and capability (like the hypothesis test utilized for the ground-level response).

*Johnson Transformation = 3.12649 + 1.61094 x Ln((X-0.0904633)/(9.24660-X))*
*(source: Minitab, See Appendix)*

The airflow dataset revealed non-normal distribution; thus, a Johnson transformation was performed (within Minitab 19) to transform the dataset to a normal distribution. The X-Bar R Control Chart leveraged in the analysis indicates that the transformed dataset are not stable (7 out of 33 data points may have special cause variation) (see Figure 6). The downside to such transformations, however, is that the original airflow measures are no longer "airflow." Indeed, this is seen by observing that some of the transformed values are negative numbers. It is not possible to have a negative airflow measurement. It is indeed possible to have negative and positive pressures, creating either push or pull airflow environments, but these directional airflows rates will still measure to an absolute value. To this extent, both the LSL and the USL were also transformed utilizing the same Johnson transformation function that changed the original dataset (shown above). As a result, the new LSL and USL are -7.93421 and 2.39379 respectively. There are no units assigned to the values, because the transformed LSL and USL are strictly representative of the new, normally distributed data. To this end, the final part of the hypothesis test (capability) provides a Z-bench score of 3.57, with a potential of 5.85. The graphical analysis in Figure 6 also shows that all measurements fall within the LSL and USL (indicating capability).

**Figure 6**: Airflow capability analysis and Xbar-R chart (for stability)



While airflow rates maybe unstable, the strong capability output (highlighted by the Z-bench score) to stay within 0 ft/s to 3.645 ft/s, makes it difficult to reject the null hypothesis. This is encouraging, because it indicates that airflow rates within fitness environments can be controlled within a range. Commonsense would seem to justify the result, however commonsense is not a defensible tool to reject or validate the research hypothesis (it can however guide assumptions). To this extent, no target was provided to further test the stability and capability of the fitness environments measured. The question of comfort vs. risk with respect to airflow and respiratory droplet diffusion will need to be debated outside this research in order to generate a recommended airflow target rate for fitness environments.

## 3.4) Other independent, face-level, variable interactions with Airflow

### **3.4.1.** Airflow as a function of ZoneType

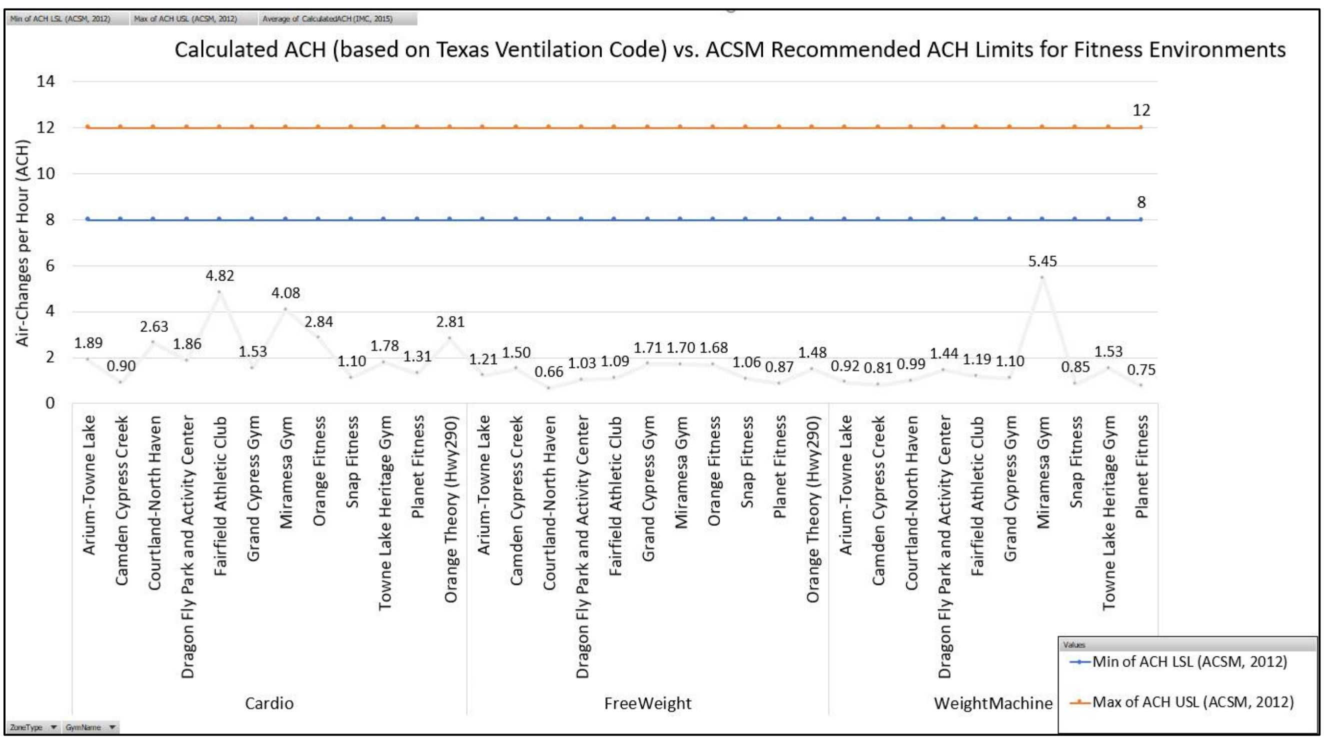
Both a HOV Levene's test (for variation) and a Mood's Median test (for centering) were conducted with the primary independent variable being ZoneType. The respective probability value for the Levene's test (P = 0.225) and for the Mood's Median test (P = 0.067) seem to indicate that the type of zone in which the measurements are taken does not statistically influence the mean airflow results (see Appendix for statistical outputs). This seems accurate, because six (6) out of twelve (12) gyms studied were small, single-room, environments (residential gyms). Some of these environments had clearly defined zones (for cardio, free weight, and weight machines) while others had mixed zones. The interaction of airflow in these smaller areas may have created a more stabilized effect on the measurements (thus biasing the results).

Residential gyms are important to the study, because many of these facilities are automatically funded through rent payments (in apartment environments) or homeowner association (HOA) dues (in planned communities). Indeed, all eight (8) of the residential fitness facilities incorporated in this study are either apartment or planned community facilities. A reasonable assumption is that membership attrition in larger fitness facilities (Planet Fitness, Snap Fitness, Orange Theory, etc.) may be offset by higher attendance in residential facilities. The current study was not designed to prove or disprove this assumption. Also, as mentioned above, there are only twelve (12) gyms defining the dataset. Expanded analysis (more fitness facilities) in future studies would enable more measurements and larger sample sizes.

### 3.5) Air-Changes per Hour (secondary response for Face-level environments)

Per Section 1.4, ceiling-level variables associated with ventilation are externalized from this research due to accessibility issues with HVAC units and measuring flow from ceiling-height ducting/vents. This externalization is important to note, because indoor air quality is governed by Texas ventilation code. Indeed, for fitness environments, the minimum ventilation required is 20 CFM per person (IMC, 2015). Additionally, the comfort vs. risk debate at the face-level (airflow) is likely to be dependent on the quality of the air within fitness environments. To provoke discussion and further study, this research predicts that if air is dirty, 0 ft/s airflow maybe ideal to reduce settling distance of respiratory droplets. If air is clean however, than a different airflow measure may be ideal to facilitate higher rates of ventilation. To not fully ignore the externalization, the research attempts to calculate a required ACH for each zone within and across the twelve (12) gyms in this study. The reference formula is described in Section 2.2 of this report. These calculated ACH values are then graphed against industry guidance from the American College of Sports Medicine. The ACSM states that fitness environments should aim to have anywhere from 8 (LSL) to 12 (USL) Air Changes per Hour (ACH) (ACSM, 2012). Figure 7 below provides a comparison of the results (based on Texas ventilation code). The output indicates that there is a gap with respect to code requirements and industry recommendation[2]. This further highlights the need to conduct actual measurements at the vents. To facilitate future analysis, the dataset submitted with this report include a count of the number of ceiling fans and the number of vents within each zone in the fitness facilities studied (see Appendix).

**Figure 7**: ACH comparison, Texas ventilation code vs. American College of Sports Medicine




### 3.5.1. Airflow as a function of Calculated ACH (continuous variable) and ZoneType

Each Calculated ACH datapoint is derived from the standard formula highlighted in Section 2.2. A parameter is the total number of people in a gym. To this extent, equipment

[2] Texas Mechanical code allows for load calculations on a capacity basis.

counts (and placements) are the basis for representing the maximum number of individuals allowed within a respective zone. This aligns with the assumption that each piece of equipment is always assumed to be manned. The total number of people is important to define in the calculation, because Texas ventilation code defines a per-person CFM requirement for the purpose of enabling proper duct and vent sizing when designing HVAC systems. Thus, a total CFM calculation is needed in order to convert a zone-volume to an ACH rate. To this end, an attempt is made to understand the connectivity between the face-level environment (airflow rates) with the ceiling-level environment (ventilation rates, dirty air to clean air exchanges) through a regression analysis. The result of the regression output (see Appendix) is provided as a heuristic, preliminary step. It is not intended to inform policy, particularly given that the current research externalizes actual measurements at the ceiling-level. Thus, any correlation between a measured value (airflow) and a calculated value (ventilation) may not be representational of an actual measured-to-measured interaction. The adjusted $R^2$ value for the model is 4.99%. This indicates that for theoretical purposes, ventilation rate is an insignificant predictor of airflow. This seems counterintuitive given the general assumption that movement of air at any level of an indoor environment is influenced by HVAC system settings and output. Additional independent variables and a true measured-to-measured interaction may produce a different result. Figure 8 provides the model equations generated through the statistical test.

**Figure 8**: Regression model (adjusted $R^2$ = 4.99%) for Airflow as a function of Air-Changes and Zone-type

**Regression Equation**

| ZoneType | |
|---|---|
| Cardio | Y-VARIABLE ZoneAirflow(ft/s) = 1.790 - 0.1434 CalculatedACH (IMC, 2015) |
| FreeWeight | Y-VARIABLE ZoneAirflow(ft/s) = 1.497 - 0.1434 CalculatedACH (IMC, 2015) |
| WeightMachine | Y-VARIABLE ZoneAirflow(ft/s) = 1.386 - 0.1434 CalculatedACH (IMC, 2015) |

## 4. Conclusion and Recommendations

### 4.1) Gyms still represent a health concern

Fitness floors are laid out improperly. So what? Beyond their return to pre-pandemic attendance levels, risk mitigation is critical for survival of these facilities. Various survey publications attest to this fact: Sami (2020) highlights results published by the International Health, Racquet, and Sports-club Association (IHRSA) which shows, that as of July 2020 gyms are experiencing anywhere from 10-50% return of their members with an average of roughly 30%. Cooper (2020) similarly published survey results conducted by Men's Health UK (July 2020) in which ~10,000 individuals were surveyed. Roughly 4 out 10 will not go back to the gym, and roughly 8 out of 10 are risk-averse even if some do intend to go back (Cooper, 2020). Further to this Rizzo (2020) published results from a survey conducted by RunRepeat (5,055 participants, August 1 through August 13, 2020) which reveals that roughly 3 out of 10 have returned to gym, 2 out of 10 have canceled their membership, and a further 4 out of 10 are considering cancelation of their membership (Rizzo, 2020). Interestingly, to combat the general sentiment of risk-aversion in fitness environments, industry promoters are conducting their own research to disprove the connectivity between COVID-19 and gym utilization. The IHRSA published results from a nationwide data analysis of gym attendance and COVID-rates and found little to no connectivity between the two variables (IHRSA, 2020). In the process the IHRSA made a blanket statement in the release of the article stating, "national study confirms it's safe to work out at the gym" (IHRSA, 2020). Chiu (2020) however highlights skepticism from medical professionals, arguing that the study referenced by the IHRSA utilized incorrect methodology and does not really provide an answer to the safe vs. not safe debate surrounding gym environments (Chiu, 2020).

### 4.2) Recommendation: Fitness floors can de-risk the environment with better cardio setups

Annually, gym members spend an average of ~$442 (pre-pandemic) (Smith, 2018). The survey results highlighted in Section 4.1 indicate general risk-aversion to returning to the gym. Further to this, the results from the ground-level hypothesis test across the gyms within the study (Section 3.1) indicate that intrusion of personal space in fitness floor setups is an issue of concern. If the intent is to maximize capacity while being socially distant, then improved equipment layouts should be required for fitness floors. Cardio zones are an ideal place to target, because they have the highest level of mean intrusion (64%, Section 3.1, Table 4) and are the most popular areas to exercise (221 out of 399 pieces of equipment belong to cardio zones). With respect to cardio equipment, Figure 5 (Section 3.2.2) shows that Treadmills (N = 94, 60% mean intrusion), Bikes (N = 47, 73% mean intrusion), and Skiers (N = 46, 58% mean intrusion) are likely the most impactful pieces of equipment to re-organize. The process for re-organizing the equipment has not been developed by this research, because each fitness floor is unique, and needs to be considered independently, however this research has provided quantitative methods for measuring risk. Fitness facility owners are encouraged to follow these methods and recommendations to reduce operational risk.

Additionally, Dbouk's (2020) findings should be considered carefully. That study shows that in 0ft/s airflow, there may be respiratory droplet particles in suspension up to roughly 2.5 ft above the ground after 49s (with a total horizontal settling distance of ~3.28 ft from the source). In 3.645 ft/s airflow, respiratory droplets can remain suspended vertically, from ~1.6 ft. to face-level (~5.3 ft.) above the ground (after traveling ~20 ft. horizontally from the source in 5s).

(Dbouk, 2020). The more equipment a fitness floor has, the more surfaces available for particle settlement. A particle that would otherwise evaporate atmospherically or settle onto the fitness floor may now find itself settled at an elevated height. Reverse thinking (equipment as a physical barrier to dispersal of respiratory droplets) is an interesting concept, however the research assumption of a fully manned gym, means that someone will either be using (or is going to use) the equipment. Thus, a gym-user would be prone to transmission, irrespective of whether or not there is equipment intersecting dirty airflow.

### 4.3) The comfort (airflow rate) vs. risk (particle settling) debate needs development

Socially distancing equipment on fitness floors is a relatively straightforward recommendation for the ground-level environment. Less straightforward is guidance on comfort vs. risk with respect to airflow at the face-level. As highlighted in Section 3.3, airflow rates at the face-level within gyms are relatively stable and predictable (capable) within the LSL (0 ft/s) and USL (3.645 ft/s). Using the Dbouk (2020) study as a general guide, the belief is that gym users can expect the settling distance of respiratory droplets to predictably fall anywhere from 3.28 ft. (0ft/s airflow) to roughly 20 ft. (3.645 ft/s airflow) from the source, irrespective of whether they are exercising in cardio, free weight or weight machine zones. Since this research does not attempt to provide a target for airflow rate (and hence an opinion on the comfort vs. risk debate) the recommendation is for further modeling to be performed at the face-level. Airflow patterns, flow direction, and ventilation rates are three important variables that impact airborne transmissivity (Qian et al, 2018). As noted in Section 1.4, ventilation is externalized from this study due to accessibility. Airflow patterns are also not modeled since the key variable of interest for this research is face-level airflow rates. Flow direction however is indirectly accounted for, because all airflow measurements conducted were taken both standing and walking, perpendicular to flow direction, to allow the digital anemometer to measure accurately. A four-variable model (airflow rate, airflow pattern, flow direction, and ventilation rates) within fitness environments is needed to provide industry guidance on risk mitigation at the face-level. Be mindful that this four-variable study may be complex. Wind corridors (due to equipment arrangement), equipment-spacing, number of vents, placement of ceiling fans, etc. are a few of the independent variables that will also require consideration.

The general counterargument for associating airflow rates and particle settling distance with active risk in fitness environments (and in fitness floor setups) is the use of facial masks. Face-masks are indeed a good, commonsense option, for mitigating the spread of respiratory droplets, however when it comes to fitness environments, the study indicates that out of twelve (12) gyms: four (4) did not have a pandemic policy, eight (8) did not have strict enforcement of the policy (member discretion) and all twelve (12) either did not require face-masks (8), or required face-masks except when exercising (4) (see Appendix).

### 4.4) Thoughts on ventilation

As reported in Section 3.5, Figure 6 provides a summary view, showing a noticeable gap between calculated Air-changes per hour required by Texas ventilation code vs. the minimum (8) and maximum (12) ACH recommendations suggested by the American College of Sports Medicine. The recommendation is for future studies to conduct actual CFM measurements at the vents and calculate actual ACH occurring against the ACSM requirement. If Figure 6 is suggestive of the expected results, then reassessment is necessary for the Texas ventilation code and/or industry sources like the ACSM.

### 4.5) Devil's advocate and research opportunity

This study primarily tested two response variables: Intrusion of personal-space for equipment (ground-level test) and Airflow rates (face-level test). A full-scale, academic research option however, likely would model additional dependent and independent variables. This research is not intended to be an answer, but rather a start for the discussion on statistically risk-profiling fitness environments. The following Sections within this report highlight opportunities for improving the potential merits of the discussion.

Section 1.4: Externalized from the study are all areas within the fitness environment outside of cardio, free weight, and weight machine zones. These externalizations are set to limit the scale of the study, however future studies may want to consider data collection and analysis of all areas (locker rooms, group fitness rooms, reception, etc.) These areas may also represent a risk, especially in medium-size and big-box gyms where reception typically shares a common space with exercise.

Section 3.2.1: Testing mean intrusion as a function of zone area is limited by the sample size. More gyms will need to be incorporated into the study to ensure that the aggregated view of "mean" intrusion still leaves enough data points for measurement (many individuals measurements will reduce to fewer average measurements).

Section 3.3: Capability analysis of airflow rates within a boundary (LSL and USL) is important to test, however the missing target-value for airflow rate is suggestive that more analysis needs to be done in order to establish an opinion on the comfort vs. risk debate.

Section 3.4.1: Mean airflow as a function of zone type is limited to the number of aggregated samples (12 gyms). Future studies should consider expanding the geographical boundary of the study to capture more fitness facilities. Additionally, it may be desirable to understand the marketplace transition of traditional big-box gyms to residential gyms to better understand if the marketplace is shifting to smaller environments.

Section 3.5.1: Regression on a measured-variable to calculated-variable (airflow rate-to-calculated ACH) may not be as accurate or representative of an actual measured-to-measured interaction. Actual measurements with an anemometer at the vents (ceiling-level) will be desirable for hypothesis testing in future studies.

#### **4.5.1.** Research opportunity: symbiotic relationship among risk response variables

Do changes in airflow rates, equipment spacing, or other environmental factors affect the measured risk across all three tiers (ground, face, and ceiling environments)? This study does not answer that question, because the sample size of the data must aggregate in order to allow for a correlation analysis (33 data points). Despite the low sample size, three tests were run on transformed airflow, intrusion, and volume measures. The correlation strength between the various variables ranged from 5.33% to 53.24% (adjusted R-square). More data are needed to get a better test of co-dependency among response variables.

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# 6. Appendix

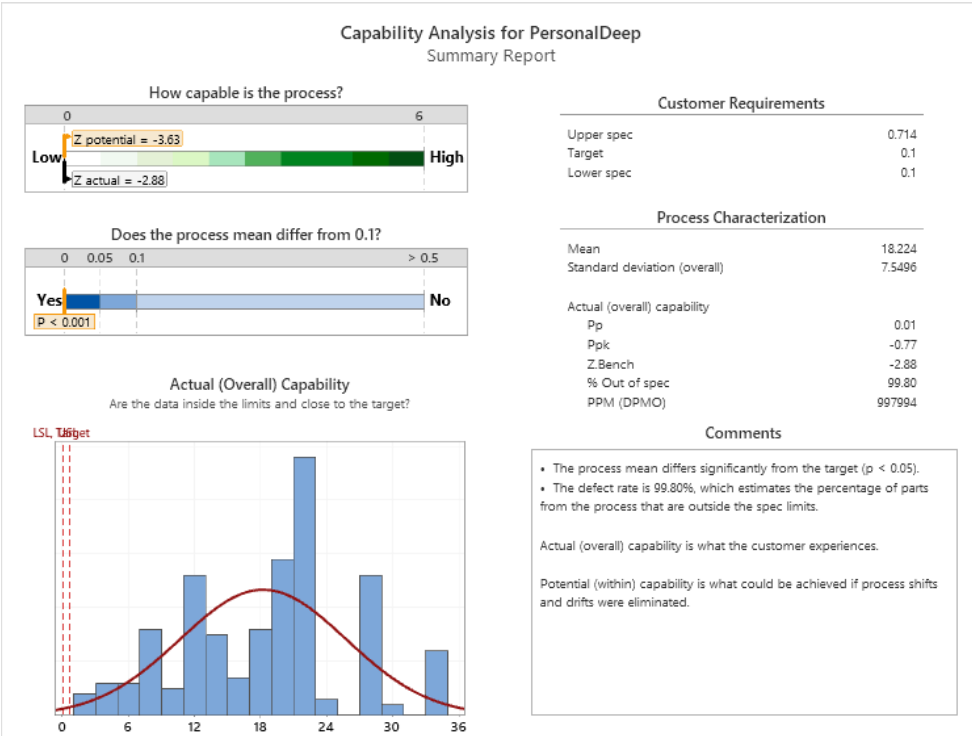
## 6.1 Appendix A (for Section 2)

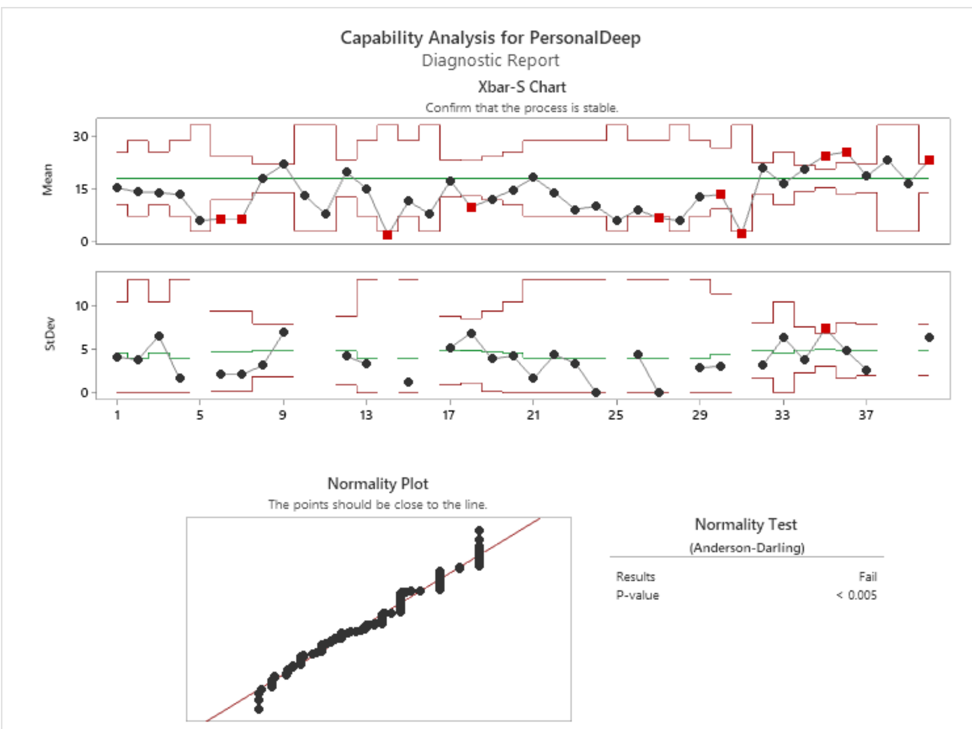
Section 2.3, **Table 3: Variable Description, Categorization, and Collection**

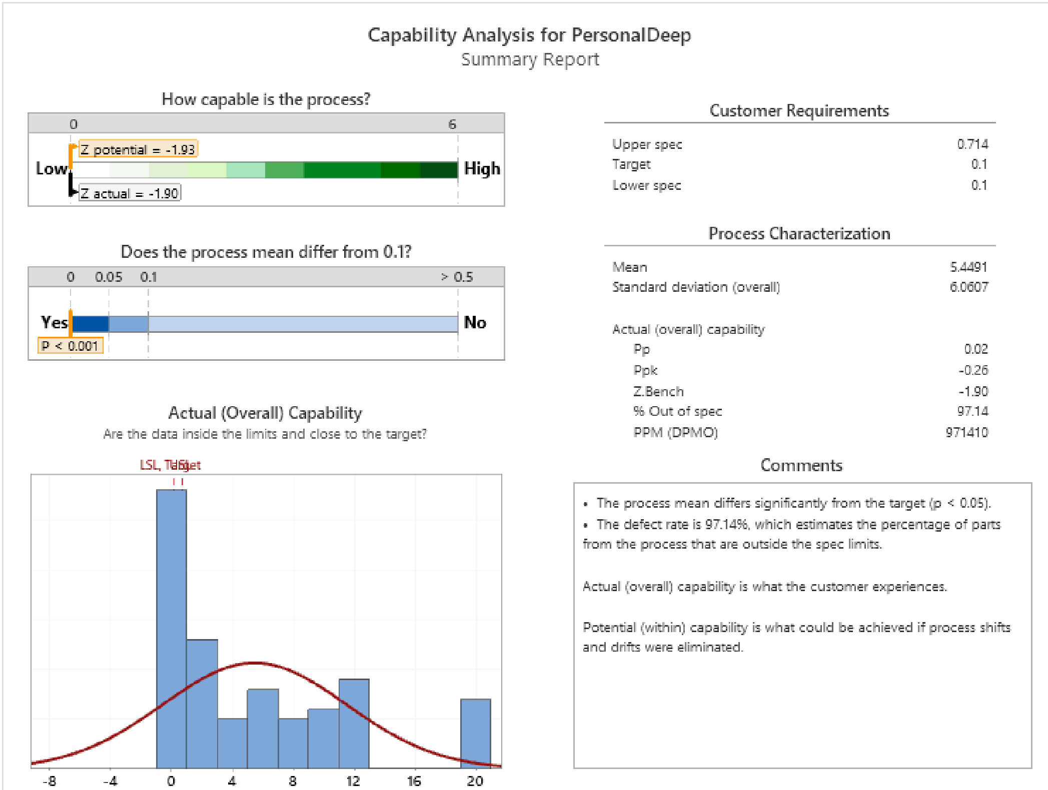
| Variable | Description | Continuous/ Discrete | Environment-level | Variable-level | Collection Method |
|---|---|---|---|---|---|
| EquipDesc | Categorization and labeling of equipment (i.e. bench 1, treadmill 1, bike 9, etc.) | Discrete | Ground-level | Secondary (Independent-X) | On-premise/virtual (i.e. Matterport software) |
| DIST Low | Gym-specific, zone specific minimum distance (ft.) measured between equipment. | Continuous | Ground-level | Secondary (Independent-X) | On-premise measurements/Harris County Engineering Building Submittals/Virtual counts (i.e. Matterport software) |
| DIST High | Gym-specific, zone specific maximum distance (ft.) measured between equipment. | Continuous | Ground-level | Secondary (Independent-X) | On-premise measurements/Harris County Engineering Building Submittals/Virtual counts (i.e. Matterport software) |
| FanCount | Gym-specific, zone-specific count of fans | Discrete | Ceiling-Level | Secondary (Independent-X) | Harris County Building plans, On-premise audit |
| VentCount | Gym-specific, zone-specific count of vents | Discrete | Ceiling-Level | Secondary (Independent-X) | Harris County Building plans, On-premise audit |

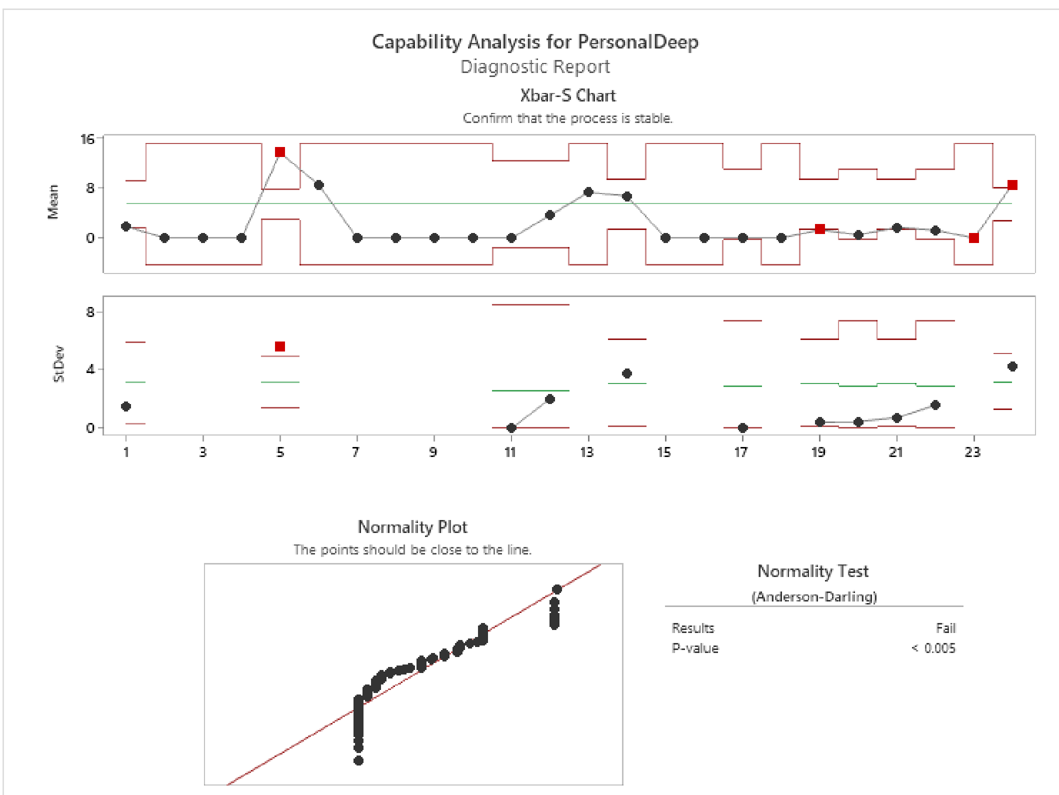
## 6.2 Appendix B (for Section 3)

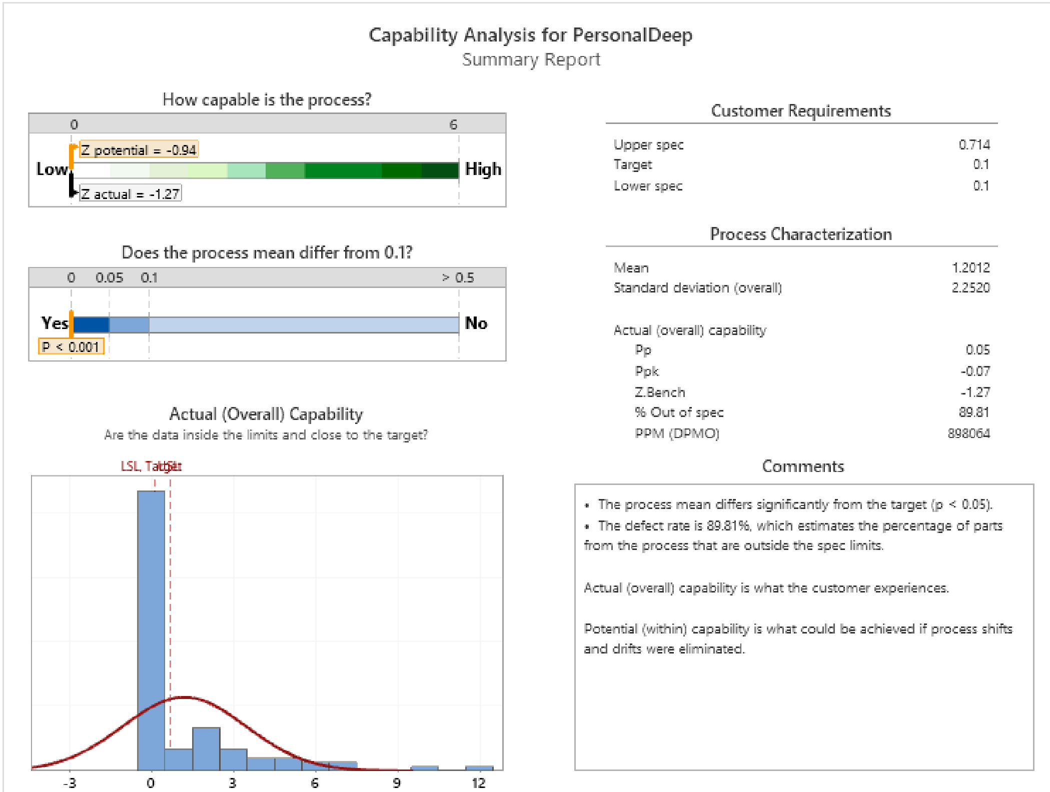
Section 3.1 data: **Minitab Outputs for Capability Analysis of non-normal data for personal-space intrusion.**

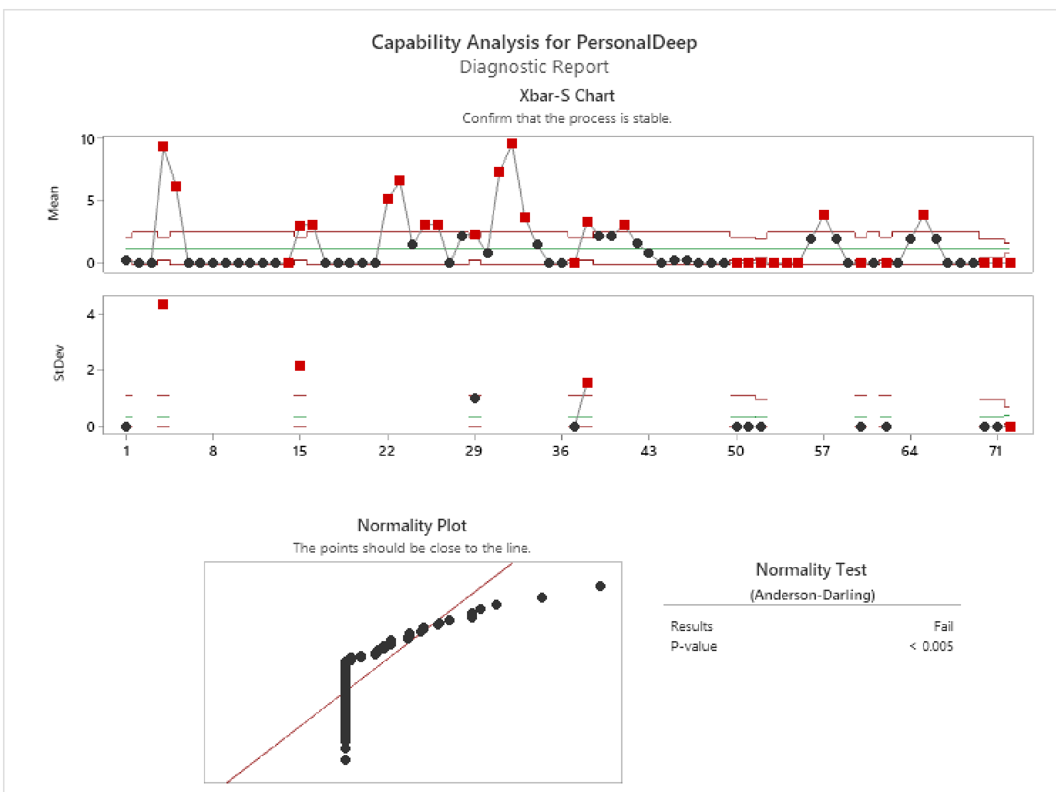



Capability Analysis for PersonalDeep
Summary Report
How capable is the process?
0
6
Low
High
Z potential = -1.93
Z actual = -1.90
Does the process mean differ from 0.1?
0 0.05 0.1 > 0.5
Yes
No
P < 0.001
Actual (Overall) Capability
Are the data inside the limits and close to the target?
LSL, Target
USL
-8 -4 0 4 8 12 16 20
Customer Requirements
Upper spec 0.714
Target 0.1
Lower spec 0.1
Process Characterization
Mean 5.4491
Standard deviation (overall) 6.0607
Actual (overall) capability
Pp 0.02
Ppk -0.26
Z.Bench -1.90
% Out of spec 97.14
PPM (DPMO) 971410
Comments
• The process mean differs significantly from the target (p < 0.05).
• The defect rate is 97.14%, which estimates the percentage of parts from the process that are outside the spec limits.
Actual (overall) capability is what the customer experiences.
Potential (within) capability is what could be achieved if process shifts and drifts were eliminated.


Capability Analysis for PersonalDeep
Diagnostic Report
Xbar-S Chart
Confirm that the process is stable.
Mean
StDev
16
8
0
4
1 3 5 7 9 11 13 15 17 19 21 23
Normality Plot
The points should be close to the line.
Normality Test
(Anderson-Darling)
Results Fail
P-value < 0.005


Capability Analysis for PersonalDeep
Summary Report
How capable is the process?
0
6
Low
High
Z potential = -0.94
Z actual = -1.27
Does the process mean differ from 0.1?
0
0.05
0.1
> 0.5
Yes
No
P < 0.001
Actual (Overall) Capability
Are the data inside the limits and close to the target?
LSL, Target
USL
-3
0
3
6
9
12
Customer Requirements
Upper spec 0.714
Target 0.1
Lower spec 0.1
Process Characterization
Mean 1.2012
Standard deviation (overall) 2.2520
Actual (overall) capability
Pp 0.05
Ppk -0.07
Z.Bench -1.27
% Out of spec 89.81
PPM (DPMO) 898064
Comments
• The process mean differs significantly from the target (p < 0.05).
• The defect rate is 89.81%, which estimates the percentage of parts from the process that are outside the spec limits.
Actual (overall) capability is what the customer experiences.
Potential (within) capability is what could be achieved if process shifts and drifts were eliminated.


Capability Analysis for PersonalDeep
Diagnostic Report
Xbar-S Chart
Confirm that the process is stable.
Mean
StDev
10
5
0
4
2
0
1
8
15
22
29
36
43
50
57
64
71
Normality Plot
The points should be close to the line.
Normality Test
(Anderson-Darling)
Results Fail
P-value < 0.005

Section 3.2.2. data: **Minitab outputs for Levene's test for cardio zones**:

## 95% Bonferroni Confidence Intervals for Standard Deviations

| X1-Variable EquipType | N | StDev | CI |
|---|---|---|---|
| Bike | 47 | 0.311678 | (0.261529, 0.39298) |
| Climber | 5 | 0.299348 | (0.096623, 1.91285) |
| Rowing Machine | 29 | 0.266561 | (0.207983, 0.37494) |
| Skier | 46 | 0.279906 | (0.236583, 0.35081) |
| Treadmill | 94 | 0.207716 | (0.171997, 0.25792) |

*Individual confidence level = 99%*

## Tests

| Method | Test Statistic | P-Value |
|---|---|---|
| Multiple comparisons | — | 0.016 |
| Levene | 3.32 | 0.012 |

**Levene's test for free weight zones:**

## 95% Bonferroni Confidence Intervals for Standard Deviations

| X1-Variable EquipType | N | StDev | CI |
|---|---|---|---|
| Abs | 8 | 0.063549 | (0.021179, 0.277243) |
| Arm | 2 | 0.213450 | (*, *) |
| Back | 1 | * | (*, *) |
| Bench | 46 | 0.238267 | (0.184108, 0.326061) |
| Cable | 1 | * | (*, *) |
| Chest | 4 | 0.000000 | (*, *) |
| Smith Machine | 5 | 0.000000 | (*, *) |
| TRX System | 14 | 0.149857 | (0.094109, 0.290448) |

*Individual confidence level = 98.75%*

## Tests

| Method | Test Statistic | P-Value |
|---|---|---|
| Multiple comparisons | — | 0.000 |
| Levene | 1.86 | 0.145 |

*Samples are omitted from the tests if their standard deviations are 0 or missing.*

## Levene's test for weight machine zones

### 95% Bonferroni Confidence Intervals for Standard Deviations

| X1-Variable EquipType | N | StDev | CI |
|---|---|---|---|
| Abs | 4 | 0.191306 | (0.0136140, 8.76315) |
| Arm | 8 | 0.063699 | (0.0316560, 0.19618) |
| Back | 12 | 0.054212 | (0.0199894, 0.19121) |
| Bench | 2 | 0.076784 | (*, *) |
| Cable | 2 | 0.000000 | (*, *) |
| Chest | 12 | 0.096177 | (0.0187061, 0.64310) |
| Leg | 34 | 0.027138 | (0.0102330, 0.07836) |
| Press | 2 | 0.020162 | (*, *) |
| Shoulder | 11 | 0.087925 | (0.0214051, 0.48290) |
| Smith Machine | 3 | 0.000000 | (*, *) |
| System | 7 | 0.077940 | (0.0198189, 0.50757) |

*Individual confidence level = 99.4444%*

### Tests

| Method | Test Statistic | P-Value |
|---|---|---|
| Multiple comparisons | — | 0.000 |
| Levene | 3.16 | 0.004 |

*Samples are omitted from the tests if their standard deviations are 0 or missing.*

## ANOVA 1-Way tests for Cardio, Free Weight, and Weight Machine zones

### Analysis of Variance

| Source | DF | Adj SS | Adj MS | F-Value | P-Value |
|---|---|---|---|---|---|
| X1-Variable EquipType | 4 | 1.331 | 0.33285 | 5.01 | 0.001 |
| Error | 216 | 14.355 | 0.06646 | | |
| Total | 220 | 15.686 | | | |

### Analysis of Variance

| Source | DF | Adj SS | Adj MS | F-Value | P-Value |
|---|---|---|---|---|---|
| X1-Variable EquipType | 7 | 0.7489 | 0.10698 | 2.67 | 0.016 |
| Error | 73 | 2.9205 | 0.04001 | | |
| Total | 80 | 3.6693 | | | |

## Analysis of Variance

| Source | DF | Adj SS | Adj MS | F-Value | P-Value |
|---|---|---|---|---|---|
| X1-Variable EquipType | 10 | 0.2646 | 0.026464 | 5.46 | 0.000 |
| Error | 86 | 0.4166 | 0.004845 | | |
| Total | 96 | 0.6813 | | | |

**Figure 3b**: 1-Way ANOVA plot of Free Weight-zone mean Personal-Space Intrusion (%) by Equipment Type across all fitness facilities

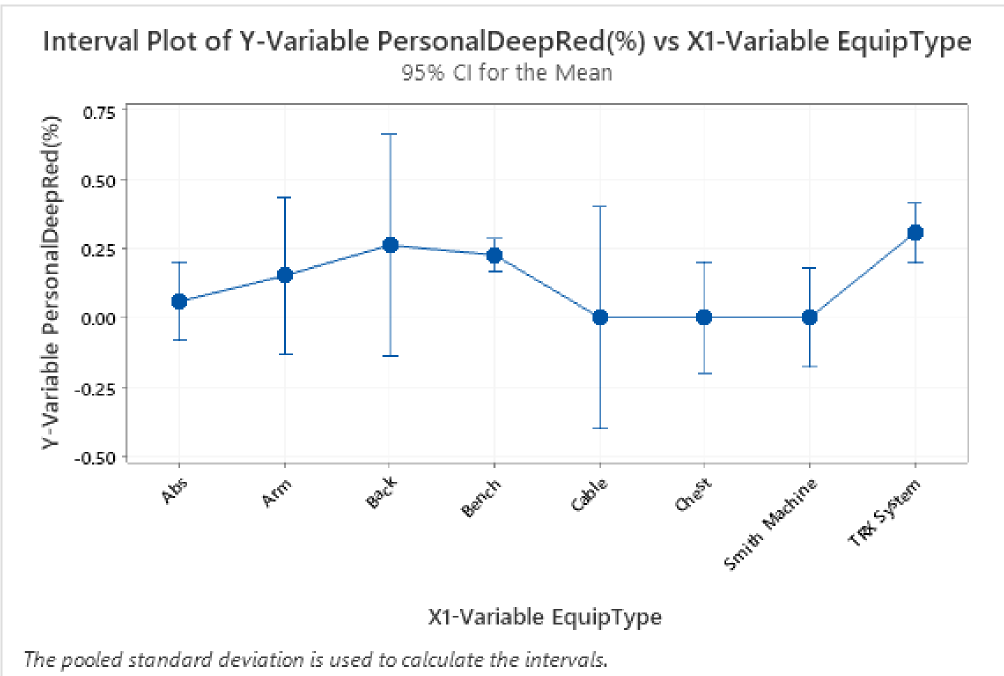
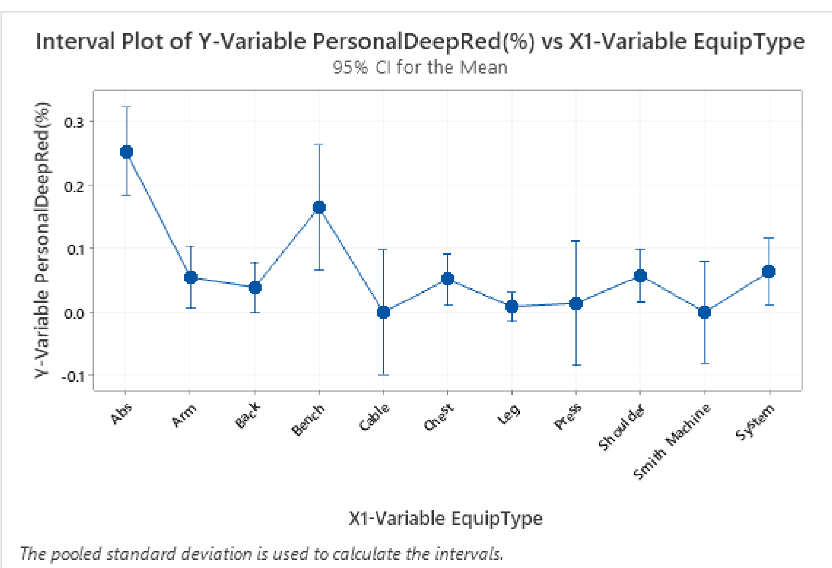


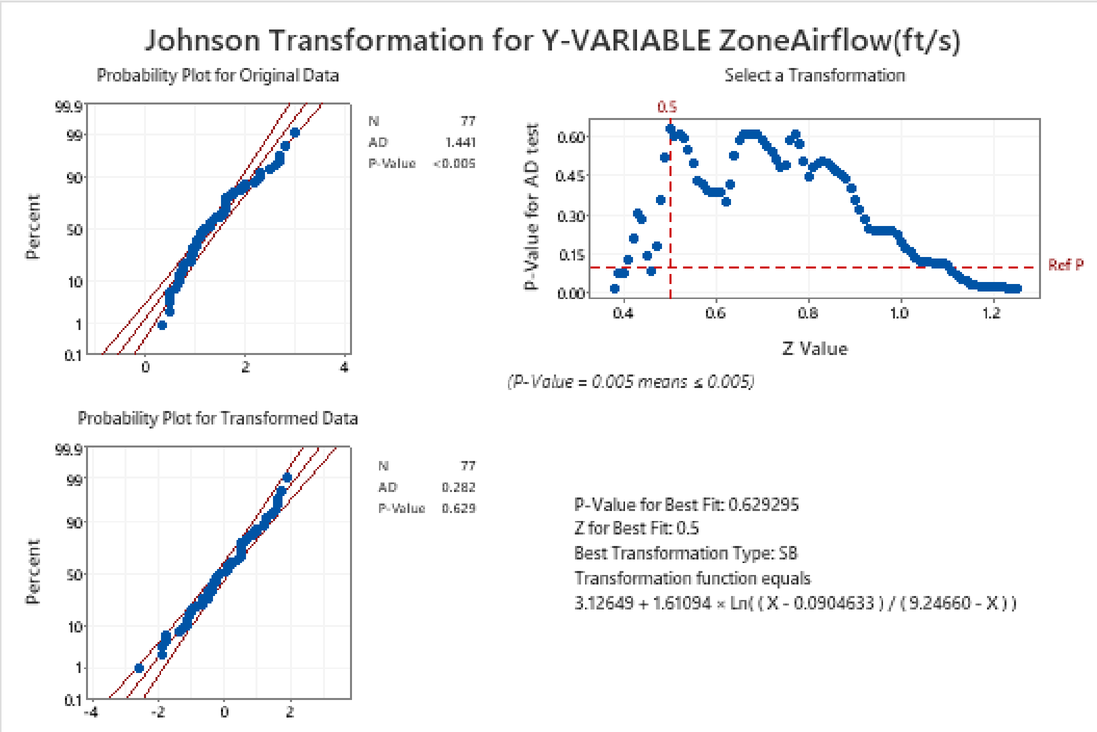

**Figure 3c**: 1-Way ANOVA plot of Weight Machine-zone mean Personal-Space Intrusion (%) by Equipment Type across all fitness facilities



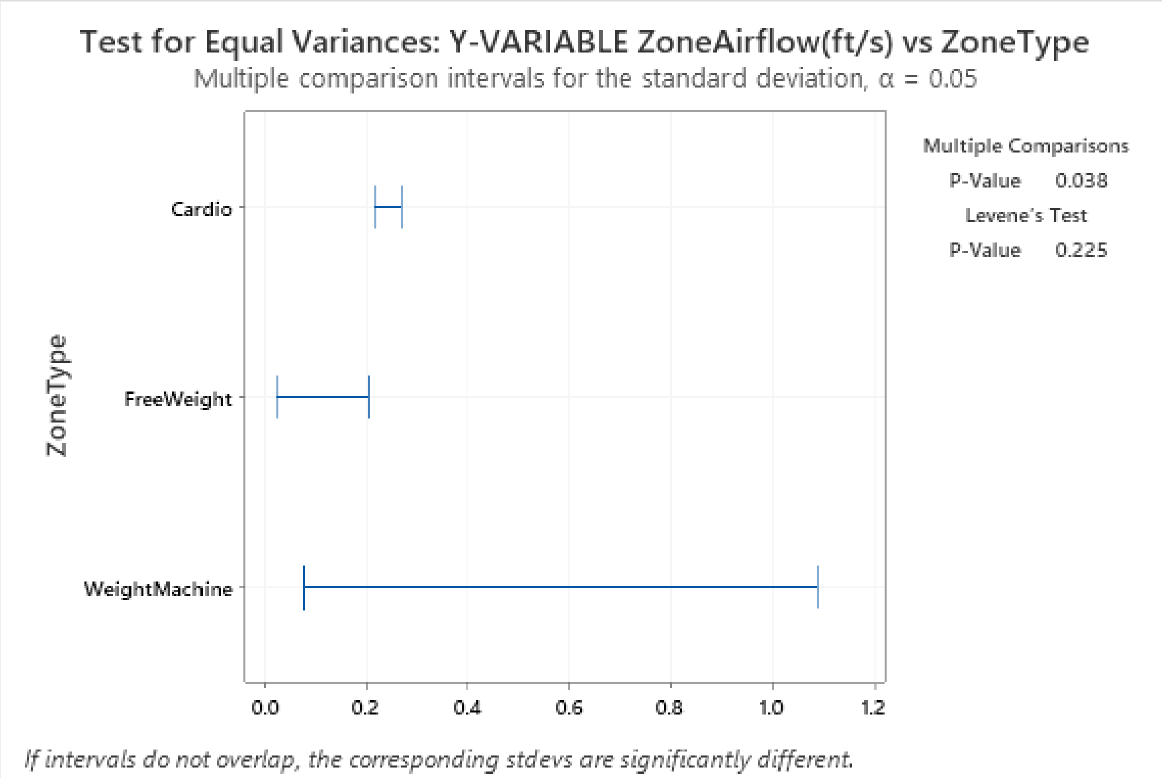
## Section 3.3, **Table of Airflow Measurements**

| GymNameShort | GymName | ZoneType | Y-VARIABLE ZoneAirflow(ft/s) |
|---|---|---|---|
| Gym D | Dragon Fly Park and Ac | Cardio | 1.03 |
| Gym D | Dragon Fly Park and Ac | Cardio | 0.96 |
| Gym D | Dragon Fly Park and Ac | Cardio | 1.17 |
| Gym D | Dragon Fly Park and Ac | Cardio | 1.03 |
| Gym D | Dragon Fly Park and Ac | Cardio | 1.1 |
| Gym D | Dragon Fly Park and Ac | WeightMachine | 1.03 |
| Gym D | Dragon Fly Park and Ac | WeightMachine | 0.96 |
| Gym D | Dragon Fly Park and Ac | WeightMachine | 1.17 |
| Gym D | Dragon Fly Park and Ac | WeightMachine | 1.03 |
| Gym D | Dragon Fly Park and Ac | WeightMachine | 1.1 |
| Gym D | Dragon Fly Park and Ac | FreeWeight | 1.058 |
| Gym S | Snap Fitness | Cardio | 2.25 |
| Gym S | Snap Fitness | Cardio | 3.01 |
| Gym S | Snap Fitness | Cardio | 1.5 |
| Gym S | Snap Fitness | Cardio | 1.3 |
| Gym S | Snap Fitness | Cardio | 0.9 |
| Gym S | Snap Fitness | WeightMachine | 0.8 |
| Gym S | Snap Fitness | WeightMachine | 0.7 |
| Gym S | Snap Fitness | WeightMachine | 0.9 |
| Gym S | Snap Fitness | FreeWeight | 0.69 |
| Gym S | Snap Fitness | FreeWeight | 0.73 |
| Gym S | Snap Fitness | FreeWeight | 1.13 |
| Gym O | Orange Fitness | Cardio | 1.59 |
| Gym O | Orange Fitness | FreeWeight | 1.58 |
| Gym O | Orange Fitness | FreeWeight | 1.6 |
| Gym O | Orange Fitness | FreeWeight | 1.59 |
| Gym F | Fairfield Athletic Club | Cardio | 0.72 |
| Gym F | Fairfield Athletic Club | Cardio | 1.09 |
| Gym F | Fairfield Athletic Club | Cardio | 1.5 |
| Gym F | Fairfield Athletic Club | Cardio | 1.7 |
| Gym F | Fairfield Athletic Club | WeightMachine | 0.75 |
| Gym F | Fairfield Athletic Club | WeightMachine | 0.48 |
| Gym F | Fairfield Athletic Club | WeightMachine | 0.51 |
| Gym F | Fairfield Athletic Club | FreeWeight | 0.75 |
| Gym F | Fairfield Athletic Club | FreeWeight | 0.48 |
| Gym F | Fairfield Athletic Club | FreeWeight | 0.51 |
| Gym T | Towne Lake Heritage ( | Cardio | 1.3 |
| Gym T | Towne Lake Heritage ( | Cardio | 1.03 |
| Gym T | Towne Lake Heritage ( | Cardio | 0.97 |
| Gym T | Towne Lake Heritage ( | WeightMachine | 1.1 |
| Gym T | Towne Lake Heritage ( | WeightMachine | 0.96 |
| Gym T | Towne Lake Heritage ( | WeightMachine | 0.76 |
| Gym T | Towne Lake Heritage ( | WeightMachine | 1.3 |
| Gym A | Arium-Towne Lake | Cardio | 2.5 |
| Gym A | Arium-Towne Lake | Cardio | 2.3 |
| Gym A | Arium-Towne Lake | WeightMachine | 2.6 |
| Gym A | Arium-Towne Lake | WeightMachine | 2.7 |
| Gym A | Arium-Towne Lake | FreeWeight | 2.8 |
| Gym A | Arium-Towne Lake | FreeWeight | 1.9 |
| Gym C | Courtland-North Have | Cardio | 1.55 |
| Gym C | Courtland-North Have | Cardio | 1.6 |
| Gym C | Courtland-North Have | WeightMachine | 1.35 |
| Gym C | Courtland-North Have | WeightMachine | 1.05 |
| Gym C | Courtland-North Have | FreeWeight | 2 |
| Gym Z | Camden Cypress Creel | Cardio | 1.75 |
| Gym Z | Camden Cypress Creel | Cardio | 1.9 |
| Gym Z | Camden Cypress Creel | WeightMachine | 2.7 |
| Gym Z | Camden Cypress Creel | WeightMachine | 1.3 |
| Gym Z | Camden Cypress Creel | FreeWeight | 2.3 |
| Gym G | Grand Cypress Gym | Cardio | 0.9 |
| Gym G | Grand Cypress Gym | WeightMachine | 0.35 |
| Gym G | Grand Cypress Gym | FreeWeight | 0.62 |
| Gym M | Miramesa Gym | Cardio | 0.7 |
| Gym M | Miramesa Gym | WeightMachine | 0.65 |
| Gym M | Miramesa Gym | FreeWeight | 0.9 |
| Gym P | Planet Fitness | Cardio | 1.78 |
| Gym P | Planet Fitness | Cardio | 1.59 |
| Gym P | Planet Fitness | Cardio | 2.01 |
| Gym P | Planet Fitness | WeightMachine | 2.2 |
| Gym P | Planet Fitness | WeightMachine | 1.4 |
| Gym P | Planet Fitness | WeightMachine | 1.37 |
| Gym P | Planet Fitness | FreeWeight | 1.25 |
| Gym P | Planet Fitness | FreeWeight | 0.96 |
| Gym Y | Orange Theory (Hwy29 | Cardio | 1.59 |
| Gym Y | Orange Theory (Hwy29 | FreeWeight | 1.58 |
| Gym Y | Orange Theory (Hwy29 | FreeWeight | 1.6 |
| Gym Y | Orange Theory (Hwy29 | FreeWeight | 1.59 |

Section 3.3, **Minitab output of Johnson Transformation of non-normally distributed airflow measurements**.



Section 3.4.1, **Minitab outputs for Levene's test and Mood's Median test on Airflow as a function of ZoneType**




**Mood's Median test**

## Descriptive Statistics

| ZoneType | Median | N <= Overall Median | N > Overall Median | Q3 – Q1 | 95% Median CI |
|---|---|---|---|---|---|
| Cardio | 0.742581 | 3 | 9 | 0.256580 | (0.637999, 0.893906) |
| FreeWeight | 0.585056 | 7 | 4 | 0.091830 | (0.554176, 0.648724) |
| WeightMachine | 0.564833 | 7 | 3 | 0.116941 | (0.526596, 0.646540) |
| Overall | 0.624987 | | | | |

## Test

| | |
|---|---|
| Null hypothesis | $H_0$: The population medians are all equal |
| Alternative hypothesis | $H_1$: The population medians are not all equal |

| DF | Chi-Square | P-Value |
|---|---|---|
| 2 | 5.39 | 0.067 |

Section 3.5, **table of vent and ceiling fan counts** (source: Harris County Engineering Records, online pictures, virtual tours, and physical onsite visits).

| Redacted Identifier | Count of Fans | Count of Vents |
|---|---|---|
| Gym D | 2 | 7 |
| Gym S | 0 | 8 |
| Gym O | 4 | 12 |
| Gym F | 14 | 12 |
| Gym T | 4 | 8 |
| Gym A | 4 | 6 |
| Gym C | 4 | 6 |
| Gym Z | 3 | 7 |
| Gym G | 3 | 5 |
| Gym M | 0 | 4 |
| Gym P | 4 | 30 |
| Gym Y | 6 | 16 |