

FMEA Report - Caroline Kolb, Tran Diep, Peter Cook					
Line #	Failure Mode	Failure Cause	Potential Effects	Design Safety	Recommendation
1	ESD initiation of flammable Acetone from human spark NOTE: This FMEA line was generated by the Hazards Analysis Supervisor	Acetone in flammable concentration • Acetone leak from processing inside the Black Box AND Human spark due to being highly charged person • Wearing non-conductive shoes • Standing on floor that is non-conductive or non-static dissipative • Wearing synthetic clothing that readily charges AND not wearing ESD/ Flame rated coveralls	Local flash fire that propagates to large fire burning acetone Severe Personnel injury resulting in third degree burns and hospitalization Other personal requiring medical attention from exposure to flash fire	Unknown at time of recommendation NOTE: Acetone is flammable in air between 2.6% and 12.8% and has minimum ESD ignition of 0.0006 Joules or 0.6 mJ NOTE: Human can generate electro-static energy in a dry environment walking across carpet for example an ESD spark containing up to 0.015 Joules of energy or 15 mJ. Which means humans can easily ESD ignite Acetone and thus there is currently no known design safety given to prevent a human ESD sparking to Acetone vapor.	Design building with conductive or static dissipative floors (Recommendation 1) Design Black Box operation where acetone is processed to do the following: • Minimize amount of acetone being processed • Alarm and shut down process if acetone leaks out in sufficient quantity (over LEL 2.5%) to create a flash fire (Recommendation 2) Develop Procedure for "Manufacturing XYZ computer board" and add the following: • Wear conductive shoes • Wear ESD/ Flame rated coveralls or lab coat • WARNING Failure to wear conductive shoes and ESD/ Flame rated coveralls or lab coat could result in ESD initiation of flammable acetone vapors and personnel injury (i.e., skin burns) (Recommendation 3)
2	Propagation of fire	Excessive quantity of acetone No containment dikes to contain acetone if there was a spill	Large, uncontained fire Severe personal injury resulting in third degree burns and hospitalization Other personal requiring medical attention from exposure to flash fire Damage to equipment and warehouse Flash fire spreading beyond the warehouse and damaging more of the plant or surrounding properties	Unknown at time of recommendation	Install containment dikes around black box Install fire extinguishers around plant (Recommendation 1) Train operator to use fire extinguishers and practice safety standards with acetone (Recommendation 2) Put up hazard rating of acetone on black box WARNING Failure to contain acetone liquid could result in a flash fire (Recommendation 3)

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3	Robot malfunction during maintenance and abnormal operation (troubleshooting)	<p>Mechanical failures</p> <p>Human errors of Integration and/or Programming</p> <p>Control Errors</p> <p>Power System Failures</p> <p>Improper Assembly and Installation</p> <p>Environmental Sources</p>	<p>Damage to robot</p> <p>Bodily injury</p> <p>Death</p>	Unknown at time of recommendation	<p>Install light curtains from SMC Electric</p> <p>If necessary to work with robot while active, the robot will be placed in manual mode while using an enabling device and operating at reduced speeds</p> <p>Lockout/tagout standard operating procedures (SOPs) and training</p> <p>(Recommendation 1)</p> <p>Require operator to wear hardhat, safety glasses and protective footwear</p> <p>Hire competent maintenance workers</p> <p>(Recommendation 2)</p> <p>WARNING Failure to follow safety procedures when working with robot application could lead to injury or death</p> <p>WARNING Failure to wear PPE could lead to injury or death</p> <p>(Recommendation 3)</p>
4	Robot sparks and catches acetone on fire	<p>Robot malfunctions</p> <p>Electrical damage</p> <p>Concentration of acetone is in explosive range</p> <p>No gas sensor attached</p> <p>Human errors of integration and/or programming</p>	<p><i>Local flash fire that propagates to large fire burning acetone</i></p> <p><i>Severe Personnel injury resulting in third degree burns and hospitalization</i></p> <p><i>Other personal requiring medical attention from exposure to flash fire</i></p> <p>Damage to robot that renders it unusable</p>	Unknown at time of recommendation	<p>Attach sensors to robot that measure acetone concentration and automatically shut off when acetone reaches LEL of 2.5%.</p> <p>Perform regular maintenance checks</p> <p>Install surge protector on energy source for robot</p> <p>(Recommendation 1)</p> <p>Emergency shut off switch in case sensor does not function</p> <p>(Recommendation 2)</p> <p>WARNING Failure to properly maintain the robot and sensors will cause robot malfunction and incorrect reading in the sensors</p> <p>(Recommendation 3)</p>
5	Human spark in drop-off	<i>No Hazard Identified</i>			

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6	<p>Robot malfunction while operator is near by</p> <p>Operator causes accidents in drop-off</p>	<p>Mechanical failure of robot Control error of robot</p> <p>Box difficult to carry</p> <p>Operator not healthy enough for work (drowsy, cold, unable to carry things,etc.)</p>	<p>Operator can get pinned by robot Operator is hit by part of the robot</p> <p>Operator is injured</p> <p>Death</p>	Unknown at time of recommendation	<p>Design conveyor belt system where the dropoff point is 2.5 m away from the maximum space of the robot and the conveyor belt stops in front of the robot. Install light curtains (presence sensing device) from SMC Electric Build safeguarded space with cage tall enough to stop any flying parts or operator from getting too close Clearly mark safeguarded space (Recommendation 1)</p> <p>Require operator to wear hardhats, safety glasses and protective footwear Have a vending machine with nondrowsy medicine that the operator can access (Recommendation 2)</p> <p>WARNING Failure to wear protective equipment could result in injury WARNING Failure to stay outside of safeguarded space will result in injury or death (Recommendation 3)</p>
7	<p>Operator drops box</p> <p>Operator touches board with bare hands</p>	<p>Box is difficult to carry (too heavy, awkward shape)</p> <p>Operator not wearing correct PPE</p>	<p>Blank boards break</p> <p>Oil from hands disrupts function of board</p>	Unknown at time of recommendation	<p>Design boxes to be 12kg or less Design boxes to be optimal for carrying with handles (Recommendation 1)</p> <p>Require operator to wear gloves and protective footwear Have a sign with the proper way to carry things (lift with your legs, not your back) (Recommendation 2)</p> <p>WARNING Failure to carry boxes correctly will lead to injury WARNING Failure to wear gloves could lead to injury or damage to product (Recommendation 3)</p>
8	Dropoff --> Damage to Equipment/Facility	<i>No Hazard Identified</i>			

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9	Robot failure because of ESD spark	ESD spark from human interaction	The robot would stop operating	Unknown at time of recommendation	<p><i>Design building with conductive or static dissipative floors</i> Ground robot (Recommendation 1)</p> <p><i>Develop Procedure for "Manufacturing XYZ computer board" and add the following:</i></p> <ul style="list-style-type: none"> • <i>Wear conductive shoes</i> • <i>Wear ESD/ Flame rated coveralls or lab coat</i> • <i>WARNING Failure to wear conductive shoes and ESD/ Flame rated coveralls or lab coat could result in ESD failure of robotic arm</i> (Recommendation 2)
10	Part of the robot breaks off and hits the operator	Mechanical failures	Bodily injury	Unknown at time of recommendation	<p>Surround robot with cage large enough to stop any flying parts Perform regular maintenance (Recommendation 1)</p> <p>Train employees to turn off power when mechanical damage is obvious (Recommendation 2)</p> <p>WARNING Failure to wear protective equipment could result in injury WARNING Failure to stay outside of safeguarded space will result in injury or death (Recommendation 3)</p>
11	Robot malfunction	<p>Mechanical failures</p> <p>Human errors of Integration and/or Programming</p> <p>Control Errors</p> <p>Power System Failures</p> <p>Improper Assembly and Installation</p>	<p>Boards are broken</p> <p>Boards aligned improperly--product compromised</p>	Unknown at time of recommendation	<p>Conveyor belt has sensors to make sure boards are placed correctly in fixture</p> <p>Highly trained professionals install robot</p> <p>Perform regular maintenane and quality checks</p>

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12	Robot is damaged Robot malfunctions and damages conveyor belt	Mechanical failures Human errors of Integration and/or Programming Control Errors Power System Failures Improper Assembly and Installation Environmental Sources	Robot is rendered unusable Conveyor belt malfunctions/ stops running	Unknown at time of recommendation	Correct/thorough installation Perform site acceptance testing before initial startup of robot application Regular maintenance and quality checks Automatic shut off with alarms if conveyor belt malfunctions/stops working
13	Flammable acetone spilling out of the black box catches human spark	Acetone container leaks due to: • Improper assembly and installation • Material failures Acetone in flammable concentration • Acetone leak from processing inside the Black Box AND Human spark due to being highly charged person • Wearing non-conductive shoes • Standing on floor that is non-conductive or non-static dissipative • Wearing synthetic clothing that readily charges AND not wearing ESD/ Flame rated coveralls	Local flash fire that propagates to large fire burning acetone Severe Personnel injury resulting in third degree burns and hospitalization Other personnel requiring medical attention from exposure to flash fire	Unknown at time of recommendation	Design building with conductive or static dissipative floors (Recommendation 1) Design Black Box operation where acetone is processed to do the following: • Minimize amount of acetone being processed • Alarm and shut down process if acetone leaks out in sufficient quantity (over LEL 2.5%) to create a flash fire • An automatic system to seal the blackbox to prevent acetone vapor from spreading out in the room. This would prevent flammable acetone vapor to get into contact with human spark. (Recommendation 2) Develop Procedure for "Manufacturing XYZ computer board" and add the following: • Wear conductive shoes • Wear ESD/ Flame rated coveralls or lab coat • WARNING Failure to wear conductive shoes and ESD/ Flame rated coveralls or lab coat could result in ESD initiation of flammable acetone vapors and personnel injury (i.e., skin burns) (Recommendation 3)

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14	Acetone spilling during maintenance	Mechanical failures Human error Power System Failures Improper Assembly and Installation	Breathing/Swallowing acetone: headaches, confusion, nausea, racing pulse, changes to the size and amount of blood cells, unconsciousness, coma Breathing a moderate to high amount of acetone can also cause nose, throat, lung, and eye irritation.	Unknown at time of recommendation	Maintenance personnel wear gloves, FRC lab coat/ coveralls and respirators (Recommendation 1) WARNING Failure to wear proper PPE could result in headaches, confusion, nausea, racing pulse, changes to the size and amount of blood cells, unconsciousness, coma WARNING Failure to wear proper PPE could result in irritation to nose, throat, lungs and eyes (Recommendation 2)
15	Acetone spilling during operations	Mechanical failures Control Errors Power System Failures Improper Assembly and Installation	Acetone is a strong chemical and could potentially dissolve the plastics in the electronic boards.	Unknown at time of recommendation	<i>Design Black Box operation where acetone is processed to do the following:</i> <ul style="list-style-type: none"> • Minimize amount of acetone being processed • Have a sensor to detect acetone spilling • Automatically stops when sensor detects acetone spilling
16	Flammable acetone spilling out of the black box and leaking into other parts of the blackbox	Mechanical Failures Control Errors Power System Failures Improper Assembly and Installation	Acetone is a strong chemical and could potentially dissolve the plastics in other parts of the blackbox, causing malfunction or permanent damage in these parts.	Unknown at time of recommendation	Design the Black Box so that other components are protected in the event of acetone spilling. <i>Design Black Box operation where acetone is processed to do the following:</i> <ul style="list-style-type: none"> • Minimize amount of acetone being processed • Alarm and shut down process if acetone leaks out in sufficient quantity (over LEL 2.5%) to create a flash fire
17	Heating mechanism gets in contact with human spark	<i>No Hazard Identified</i>			
18	Heating mechanism overheats during maintenance	Mechanical failures Control Errors Power System Failures Improper Assembly and Installation	Operator gets burned by heating mechanism	Unknown at time of recommendation	Only get a heating mechanism that is capable of reaching temperature of 180F, maximum (Recommendation 1) If impossible, use a warning sign that says the machine can reach certain high temperatures (Recommendation 2)

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19	Heating mechanism overheats or fails to heat during production	Mechanical failures Control Errors Power System Failures Improper Assembly and Installation	Melts computer board If temperature is too low, the board is not processed correctly	Unknown at time of recommendation	Use a heating mechanism that is not capable of reaching temperatures that would damage the board Perform regular performance evaluations and cleanings to ensure heating
20	Heating mechanism overheats	Mechanical failures Control Errors Power System Failures Improper Assembly and Installation	Melts the heating mechanism itself	Unknown at time of recommendation	Use a heating mechanism that is only capable of reaching temperatures below the melting point of its materials

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21	<p>ESD from a human spark transferred to sensitive electronic computer board</p> <p>ESD from plastic packages transferred to electronic computer board</p>	<p>Electronic computer board is in contact with human spark.</p> <p>Plastic bags are common sources of static electricity and come in contact with the computer board</p>	<p>Lasting damage or immediate failure of the electronic boards.</p>	<p>Unknown at time of recommendation</p>	<p><i>Design building with conductive or static dissipative floors</i> Use PFM Falcon Horizontal Flow Wrapper from Frain Industries to pack the computer boards. Use static dissipative mat on conveyor belt in packaging machine to negate ESD possibility. Use antistatic bubble wrap from Grainger (Recommendation 1)</p> <p>Design work area with static dissipative mats and antistatic bracelets Require workers to wear antistatic finger cots WARNING: Failure to wear antistatic bracelets and finger cots can result in ESD damage (Recommendation 2)</p> <p>Develop Procedure for "Manufacturing XYZ computer board" and add the following: <i>Wear conductive shoes</i> <i>Wear ESD/ Flame rated coveralls or lab coat</i> WARNING Failure to wear conductive shoes and ESD/ Flame rated coveralls or lab coat could result in ESD initiation of flammable acetone vapors and personnel injury (i.e., skin burns) WARNING: Failure to wear conductive shoes and ESD coveralls or lab coat can result in ESD damage to product (Recommendation 3)</p>
22	<p>Board is still hot and burns operator</p> <p>Operator is poked by board</p>	<p>Not enough time between heating element and packing station</p> <p>Wrong orientation of board on conveyor belt</p>	<p>Operator cannot continue work (for the day)</p> <p>Bodily harm</p>	<p>Unknown at time of recommendation</p>	<p>Determine the amount of time needed for the board to cooldown and make changes as necessary (reduce speed of conveyor belt or lengthen distance between heating and packing) Conveyor belt has sensors to make sure boards are placed correctly in fixtures (Recommendation 1)</p> <p>Have operator(s) wear antistatic finger cots WARNING Failure to wear finger cots could result in burns (Recommendation 2)</p>

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23	<p>Operator drops product</p> <p>If using packing machine, it could malfunction (throws product off, desyncs and cuts product, stops working, etc)</p>	<p>Operator(s) is not healthy (tired, drowsy, has a cold, etc)</p> <p>If using conveyor belt, mechanical malfunctions, environmental factors, power system failures, improper assembly or programming</p>	Board is rendered unusable	Unknown at time of recommendation	<p>Trained professional install packing machine</p> <p>Perform regular maintenance</p> <p>Have warning system if it begins to malfunction (Recommendation 1)</p> <p>Have vending machines with nondrowsy medicine for operator(s) to use when feeling sick</p> <p>Emphasize the importance of health in work meetings (Recommendation 2)</p> <p>WARNING Working when you do not feel well could result in feeling worse and making errors. Go home (Recommendation 3)</p>
24	If using packing machine, damage to machine itself	<p>Mechanical failures</p> <p>Human errors of Integration and/or Programming</p> <p>Control Errors</p> <p>Power System Failures</p> <p>Improper Assembly and Installation</p> <p>Environmental Sources</p>	Packing machine is rendered unusable	Unknown at time of recommendation	<p>Trained professional install packing machine</p> <p>Regular maintenance and quality checks</p> <p>Automatic shut off with alarms if packing machine malfunctions/stops working (Recommendation 1)</p> <p>Train operator to notice signs of failure, power off machine and report (Recommendation 2)</p>