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شرکت ملی گاز ایران

مدیریت پژوهش و فنآوری

امورتدوین استانداردها

IGS

دستورالعمل

تحلیل علل ریشه ای خرابی

Root Cause Failure Analysis (RCFA)

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دفترمدیرعامل

شرکت ملی گازایران

تاریخ : ۱۴۰۱/۰۶/۳۰
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ابلاغ مصوبه هیأت مدیره

مدیـر محتـرم پژوهـش و فنـاوری

باسلام،

بـــه استحضـــار مـــی‌رســـانـــد در جلسـه ۱۹۷۹ مـورخ ۱۴۰۱/۰۶/۱۳ هیـات مـــدیره، نامه شماره گ۸۲۱۰۴/۰۰۰/۹ مورخ ۱۴۰۱/۰۶/۰۶ مدیر پـژوهش و فنـاوری درمـورد تصـویب نهـایی مقررات فنی شرکت ملی گاز ایران به شرح زیر مطرح و مورد تصویب قرار گرفت.

۱-دستورالعمل تحلیل علل ریشه ای خرابی (RCFA)

IGS-O-MN-003(0)

سیدمحمد پیشوایی
دبیر هیات مدیره

رونوشت : مدیرعامل محترم شرکت ملی گاز ایران و رئیس هیات مدیره
اعضای محترم هیات مدیره
مشاور و رئیس دفتر محترم مدیرعامل
سرپرست محترم امور حقوقی
رئیس محترم حسابرسی داخلی
رئیس محترم امور مجامع

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پیشگفتار

۱. این استاندارد/ دستورالعمل به منظور استفادهٔ اختصاصی در شرکت ملی گاز ایران و شرکت های فرعی وابسته تهیه شده است.

۲. شرکت ملی گاز ایران در مورد نیازهای عمومی از استانداردهای وزارت نفت (IPS) و در مورد نیازهای تخصصی از استانداردهای اختصاصی خود (IGS) استفاده می‌کند.

۳. استانداردهای شرکت ملی گاز ایران (IGS) با نظارت کمیته‌های تخصصی استاندارد، متشکل از کارشناسان و مشاوران بخش های مختلف تهیه و پس از تائید شورای استاندارد (منتخب هیأت مدیره شرکت ملی گاز ایران) به تصویب هیأت مدیره شرکت ملی گاز می‌رسند.

۴. در تنظیم متن استانداردهای (IGS)، از همهٔ منابع شناخته شده و معتبر علمی، اطلاعات فنی-تخصصی مربوط به صنایع گاز دنیا، مشخصات فنی تولیدات سازندگان معتبر جهانی و نیز از نتیجه پژوهش ها و تجارب کارشناسان داخلی بر حسب مورد استفاده می‌شود. همچنین به منظور استفاده از هر چه بیشتر از تولیدات ملی، قابلیت های سازندگان داخلی نیز مورد توجه قرار می‌گیرد.

۵. استانداردها به طور متوسط هر ۵ سال یک بار و یا در صورت ضرورت، زودتر، بازنگری و به روز رسانی می شود. بنابراین کاربران باید همیشه آخرین نگارش را مورد استفاده قرار دهند.

۶. هرگونه نظر و یا پیشنهاد اصلاح در مورد استانداردها مورد استقبال و بررسی قرار خواهد گرفت و پس از تأیید، استاندارد مربوطه نیز بازنگری خواهد شد.

۷. تحلیل علل ریشه‌ای رویداد (RCA) فرآیندی سیستماتیک است که به شناسایی عواملی که در وقوع رویداد مورد نظر مشارکت دارند، می‌پردازد. هدف از تحلیل علل ریشه‌ای رویداد آن است که، علل ریشه‌ای به گونه‌ای کشف شوند که احتمال رخ داد آنها یا پیامد آنها در صورت وقوع، کاهش یابد.

۸. تمایز تحلیل علل ریشه‌ای، در تحلیل رویداد گذشته است. با این حال، آگاهی از علل ریشه‌ای رویداد گذشته، می‌تواند باعث بهبود وضعیت آینده شود.

۹. این استاندارد برای تحلیل علل ریشه‌ای رویداد و هرگونه عدم تطابق با شرایط استاندارد یا الزامات در طول چرخه عمر کلیه دارایی های شرکت ملی گاز ایران تدوین گردیده است. و شامل موارد ذیل می‌باشد:

۹-۱- تشریح اصول تحلیل علل ریشه‌ای (RCA)

۹-۲- مشخص کردن مراحل فرآیند تحلیل علل ریشه‌ای (RCA)

۹-۳- معرفی ویژگی‌هایی برای تکنیک‌های تحلیل علل ریشه‌ای (RCA) در راستای کمک به انتخاب روش مناسب

۹-۳- تشریح تکنیک‌های تحلیل علل ریشه‌ای (RCA) و نقاط قوت و ضعف

۹-۴- تحلیل علل ریشه‌ای رویداد با پیامدهای مثبت و منفی

۹-۵- این استاندارد به منظور ارایه رویه‌های مناسب در اجرای تحلیل علل ریشه‌ای رویداد (RCA)تدوین گردیده است. شرکت‌ها می‌بایست در چارچوب و براساس این استاندارد، متناسب با ماهیت عملیاتی و کسب و کار خود، دستورالعمل‌های لازم را تهیه و اجرا نمایند.

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فهرست

عنوان **صفحه**

پیشگفتار ۱
۱- هدف و دامنه کاربرد ۴
۲- منابع ۴
۳-تعاریف و اصطلاحات ۴
۴- مراحل و الزامات فرآیند تحلیل علل ریشه‌ای (RCA): ۸
۴-۱- مرحله آغاز (Initiation) ۹
۴-۲- مرحله تعیین حقایق/وقایع ۱۰
۴-۲-۱- شواهد فیزیکی ۱۰
۴-۲-۲- شواهد انسانی ۱۰
۴-۲-۳- شواهد اسنادی ۱۱
۴-۲-۴- نمونه هایی از شواهد ۱۱
۴-۳- مرحله تحلیل ۱۱
۴-۳-۱-ویژگی‌های اعضای تیم تحلیل ۱۲
۴-۳-۲- انواع مدل‌های تحلیل ریشه‌ای ۱۲
۴-۳-۳- انواع تکنیک‌های تحلیل علل ریشه‌ای ۱۵
۴-۴- مرحله تایید ۱۷
۴-۵- مرحله ارایه نتایج ۱۸
۴-۶- گردش کار و توصیف فرآیند تحلیل علل ریشه‌ای (RCA) : ۱۹
۴-۷- توصیف فرآیند تحلیل علل ریشه‌ای (RCA) : ۲۱
۴-۷-۱- ورودی فرآیند ۲۴
۴-۷-۲- ویژگی‌های اعضای کمیته تحلیل علل ریشه‌ای رویدادها ۲۵
۴-۷-۳- منابع اطلاعات (مستندات / سوابق / شواهد) مورد نیاز برای تحلیل ۲۵

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۴-۷-۴- ارزیابی اثربخشی اجرای RCA ۲۶
۴-۷-۵- ارایه نتایج ۲۷
۴-۷-۶- مستندات و سوابق ۲۷
پیوست‌ها (اطلاعی) ۲۹

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۱- هدف و دامنهٔ کاربرد

هدف از تدوین این استاندارد، تبیین فرآیند سیستماتیک تحلیل علل ریشه‌ای رویداد از طریق شناسایی رویدادها به منظور حصول اطمینان از کشف علل ریشه‌ای، تعیین و اجرای موفق راهکارهایی است که در جهت جلوگیری از تکرار مجدد، کاهش شدت اثر آن رویدادها در آینده می‌باشد.

دامنه کاربرد این استاندارد برای تحلیل علل ریشه‌ای رویدادها (خرابی و رخداد با پیامدهای مثبت یا منفی) و هرگونه عدم تطابق با شرایط استاندارد یا الزامات در طول چرخه عمر کلیه تجهیزات و تاسیسات و دارایی‌ها در سطح شرکت ملی گاز و شرکت‌های فرعی زیرمجموعه می باشد.

۲- منابع

1. BS-EN-62740:2015, Root Cause Analysis (RCA).
2. Root Cause Failure Analysis Procedure, Iranian Gas Transmission Company, ENG-PR-08(1)
3. DEA-DSM-RCA-01, Root Cause Analysis Procedure, Petroleum Industry.
4. MOP-DSM-001, Physical Asset Management Legal, Petroleum Industry.
5. BS-EN-13306:2017, Maintenance - Maintenance Terminology

۳- تعاریف و اصطلاحات

۳-۱ در متن این استاندارد (IGS)[۱] از تعاریف و اصطلاحات زیر استفاده می‌شود:

۱. وزارت: منظور وزارت نفت جمهوری اسلامی ایران می‌باشد؛

۲. نت: نگهداری و تعمیرات؛

۳. اداره کل: منظور اداره کل نظام مدیریت دارایی های فیزیکی صنعت نفت می باشد؛

۴. شرکت اصلی: منظور شرکت ملی گاز ایران می باشد؛

۵. شرکت‌های فرعی زیر مجموعه: منظور شرکت‌های فرعی شرکت ملی گاز یران شامل شرکت‌های مهند سی و توسعه گاز، شرکت‌های پالایش گاز، شرکت انتقال گاز و شرکت‌های گاز استانی است.

۶. علت (Cause): شرایط یا مجموعه ای از شرایط که منجر به خرابی یا موفقیت می‌شوند.

- نکته۱- علت ممکن است در خلال مراحل مختلف چرخه عمر (تعیین مشخصات، طراحی، ساخت، نصب، بهره برداری و نگهداشت) به وجود بیاید.[۲]

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[۱] آدرس اینترنتی (http://igs.nigc.ir) ، آدرس الکترونیکی (igs@nigc.ir)

[۲] **Cause:** circumstance or set of circumstances that leads to failure or success.

Note 1 to entry: A cause may originate during specification, design, manufacture, installation, operation or maintenance

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۷. عامل علّی (Casual Factor): وضعیت، فعالیت، رویداد یا حالتی که برای وقوع رویداد مورد نظر، ضروری است یا در رخداد آن مشارکت دارد.[۳]

۸. عامل همکار(Contributory Factor): وضـــعیت، فعالیت، رویداد یا حالتی که در ارتباط با وقوع رویداد، عامل ثانویه در نظر گرفته می‌شود.[۴]

۹. رویداد: رخداد یا تغییر مجموعه‌ای از شـرایط که منجر به خسـارت به دارایی های فیزیکی گردد یا می‌توانسـت پتانسیل ایجاد خسارت یا آسیب را داشته باشد.

- نکته ۲- یک رویداد می‌تواند یک رخداد یا تعداد رخدادهای بیشتری باشد و علت‌های متعددی داشته باشد.
- نکته ۳- یک رویداد می‌تواند شامل آیتم هایی شود که رخ ندهند.
- نکته ۴- یک رویداد می‌تواند گاهی اوقات به عنوان شبه حادثه (Near miss) یا حادثه (Accident) درنظر گرفته شود.[۵]
- نکته ۵- یک رویداد می‌تواند شـامل عدم انطباق باشـد که به معنی انحراف و برآورده نشـدن الزامات و انتظارات می‌باشد.

۱۰. خرابی(Failure): عدم توانایی تجهیزات و تاسیسات برای عملکرد مطابق با الزامات و انتظارات تعیین شده

- نکته ۶- خرابی یک آیتم، رویدادی است که از خطای آن آیتم، حاصل می‌شود.
- نکته ۷- صفت هایی از قبیل فاجعه بار، بحرانی، اصلی، فرعی، اندک و چشم گیر ممکن است برای دسته بندی خرابی‌ها براساس شدت پیامدها استفاده شود. انتخاب و تعاریف معیار های شدت، بستگی به نوع کاربرد و میزان حساسیت دارد.
- نکته ۸- صفت هایی از قبیل استفاده های نادرست،کنترل نادرست و نقطه ی ضعف، ممکن است برای دسته بندی خرابی‌ها بر اساس علت خرابی، استفاده شوند.[۶]

۱۱. سازوکار خرابی: (Failure Mechanism) فرآیندی که منجر به خرابی می‌شود.

- نکته۹- فرآیند می‌تواند فیزیکی، شیمیایی، منطقی، روانشناختی و یا ترکیبی از آنها باشد.[۷]

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[۳] **Causal Factor:** condition, action, event or state that was necessary or contributed to the occurrence of the focus event

[۴] **Contributory Factor:** condition, action, event or state regarded as secondary, according to the occurrence of the focus event

[۵] **Event:** occurrence or change of a particular set of circumstances

Note 2 to entry: An event can be one or more occurrences, and can have several causes.

Note 3 to entry: An event can consist of something not happening.

Note 4 to entry: An event can sometimes be referred to as an “incident” or “accident”.

[۶] **Failure** <**of an item**>: loss of ability to perform as required

Note 1 to entry: A failure of an item is an event that results in a fault of that item.
Note 2 to entry: Qualifiers, such as catastrophic, critical, major, minor, marginal and insignificant, may be used to categorize failures according to the severity of consequences, the choice and definitions of severity criteria depending upon the field of application.
Note 3 to entry: Qualifiers, such as misuse, mishandling and weakness, may be used to categorize failures according to the cause of failure.
Note 4 to entry: This is failure of an item, not more generally of behavior.

[۷] **Failure Mechanism:** process that leads to failure

Note 1 to entry: The process may be physical, chemical, logical, psychological or a combination thereof.

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۱۲. رویداد اصلی: رویدادی است که به منظور تشریح علّی، مدنظر قرار می‌گیرد.

۱۳. عامل علّی بی واسطه : وضعیت، فعالیت، رویداد یا حالتی که هیچ عامل علّی دیگری بین این عامل علّی و رویداد مورد نظر وجود ندارد.

- نکته۱۰- وجود بیش از یک عامل علّی بی واسطه محتمل می‌باشد.[۸]

۱۴. عامل علّی لازم: تغییر شرایط، فعالیت یا حالتی که پتانسیل ایجاد رویداد را داشته باشد.[۹]

۱۵. خطای انسانی: تناقض مابین اقدام انسانی انجام گرفته و یا صورت نگرفته با آنچه که مورد انتظار و نیاز است.

- نکته ۱۱- اشتباه نوعی از خطای انسانی است.
- نکته ۱۲- خطای انسانی برای هر موقعیتی که نتایج و خروجی مد نظر حاصل نشده است، فارغ از صحت و سقم نیت شخص، بکار برده می‌شود.[۱۰]

۱۶. آیتم: موضوع مد نظر

- نکته ۱۳- آیتم ممکن است قطعه مجزا، اجزا، دستگاه، واحد عملکردی، تجهیز، زیرسیستم و یا سیستم باشد.
- نکته ۱۴- آیتم ممکن است شامل سخت افزار، نرم افزار، نیروی انسانی یا ترکیبی از آنها باشد.
- نکته ۱۵- آیتم در اغلب موارد شامل عناصری است که ممکن است هرکدام به صورت مجزا در نظر گرفته شوند.[۱۱]

۱۷. علت ریشه‌ای(Root Cause): عامل علّی نهایی که با هدف تحلیل مرتبط است.

- نکته ۱۶- یک رویداد اصلی معمولاً می‌تواند بیشتر از یک علت ریشه‌ای داشته باشد.
- نکته ۱۷- در برخی از زبان‌ها ، عنوان علت ریشه‌ای به ترکیبی از عوامل علّی اطلاق می‌شود که علل ریشه‌ای قبلی نداشته باشند.[۱۲]

---

[۸] **Immediate causal factor:** condition, action, event or state where there is no other causal factor between this causal factor and the focus event
Note 1 to entry: There may be more than one immediate causal factor.

[۹] **Necessary causal factor** <**of an event or state**>: condition, action, event or state, that resulted in the given event or state, without which the given event or state would not have occurred

[۱۰] **Human error:** discrepancy between the human action taken or omitted, and that intended or required
Note 1 to entry: The first edition of IEC 60050-191:1990 identified “mistake” as a synonym for "human error", but a mistake is a type of human error.
Note 2 to entry: The term human error applies to any situation where the outcome is not as intended whether the intent of the person was correct or not.

[۱۱] **Item:** subject being considered
Note 1 to entry: The item may be an individual part, component, device, functional unit, equipment, subsystem, or system.
Note 2 to entry: The item may consist of hardware, software, people or any combination thereof.
Note 3 to entry: The item is often comprised of elements that may each be individually considered.

[۱۲] **Root cause:** causal factor with no predecessor that is relevant for the purpose of the analysis
Note 4 to entry: A focus event normally has more than one root cause.
Note 5 to entry: In some languages, the term root cause refers to the combination of causal factors which have no causal predecessor (a cut set of causal factors)

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۱۸. تحلیل علت ریشه‌ای(Root Cause Analysis): فرآیندی نظام‌مند، برای شناسایی علت‌های ریشه‌ای یک رویداد اصلی[۱۳]

۱۹. ذینفعان (Stakeholders): افراد و یا سازمانی که می‌تواند اثر گذار باشد یا تحت تاثیر قرار گیرد یا توسط یک تصمیم یا فعالیت خودش تحت تاثیر قرار می‌گیرد.[۱۴]

۲۰. اصل توقف (Stopping Rule): اصول مستدل و صریح جهت تعیین این‌که چه زمانی یک عامل علّی به عنوان یک علت ریشه‌ای، تعریف می‌شود.[۱۵]

۲۱. کمیته تحلیل علل ریشه‌ای: کمیته‌ای متشکل از اعضای آموزش دیده و آشنا با استاندارد/تکنیک‌های تحلیل علل ریشه‌ای می‌باشد.

۲۲. تسهیل‌گر(Facilitator): شخصیتی حقیقی آموزش دیده مسلط به استاندارد/تکنیک‌های تحلیل علل ریشه‌ای که در شناسایی عیوب و مشکلات و اجرای صحیح الزامات این استاندارد کمک و راهنمایی می نماید.

۲۳. رییس کمیته تحلیل علل ریشه‌ای رویداد: شخصیتی حقیقی یا حقوقی و آشنا با استاندارد/تکنیک‌های تحلیل علل ریشه‌ای که از طرف مدیریت ارشد سازمان تعیین و مسئولیت راهبری فرآیند تحلیل علل ریشه‌ای را بر عهده دارد.

۲۴. دبیر کمیته تحلیل علل ریشه‌ای رویداد: مسئولیت هماهنگی جلسات و مستندسازی فعالیت‌های کمیته برعهده دبیر کمیته تحلیل بوده و رییس کمیته RCA دبیر کمیته تحلیل مورد نظر را تعیین می نماید.

۲۵. تعیین سطح تحلیل: تحلیل و ارزیابی می‌تواند در سطوح شرکت ملی گاز ایران و شرکت‌های فرعی زیرمجموعه انجام شود. تعیین سطح تحلیل و ارزیابی آن بر اساس معیارهای آستانه ای و درجه بندی رویدادها صورت می‌گیرد. مسئولیت این موضوع بر عهده رییس کمیته RCA شرکت‌های فرعی می‌باشد.

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[۱۳] **Root cause analysis (**RCA): systematic process to identify the causes of a focus event

[۱۴] **Stakeholder:** person or organization that can affect, be affected by, or perceive themselves to be affected by a decision or activity

[۱۵] **Stopping rule:** reasoned and explicit means of determining when a causal factor is defined as being a root cause

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۴- مراحل و الزامات فرآیند تحلیل علل ریشه‌ای (RCA):

مراحلی به صورت سیستماتیک به منظور شناسایی علل ریشه‌ای رویدادها براساس بررسی مستندات و شواهد و ارایه راهکار واثربخشی نتایج می‌باشد و شامل موارد زیر است. مراحل تحلیل علل ریشه‌ای مطابق جدول ۱ و شکل ۱ می‌باشد:

جدول ۱: مراحل تحلیل علل ریشه‌ای رویداد

مراحل فرآیند	شرح
آغاز (Initiation)	ضـــرورت انجام فرآیند RCA و تعریف اهداف و محدوده کار بر اساس دانش موجود در خصوص رویداد اصلی
ســـازماندهی حقایق/وقایع (Establishing Facts)	جمع آوری داده‌ها، سازماندهی و تعیین حقایق/وقایع در پا سخ به سوالات: چه چیزی، کجا، چه زمانی، توسط چه کسی؟
تجزیه و تحلیل (Analysis)	تحقیق چگونگی و چرایی علل رویداد ا صلی با ا ستفاده از مدل‌ها، ابزارها و تکنیک‌های RCA
صحه گذاری (Validation)	اعتبارسنجی راه حل‌های مختلف
ارایه نتایج (Presentation of Result)	ارایه نتایج تحلیل رویداد اصلی

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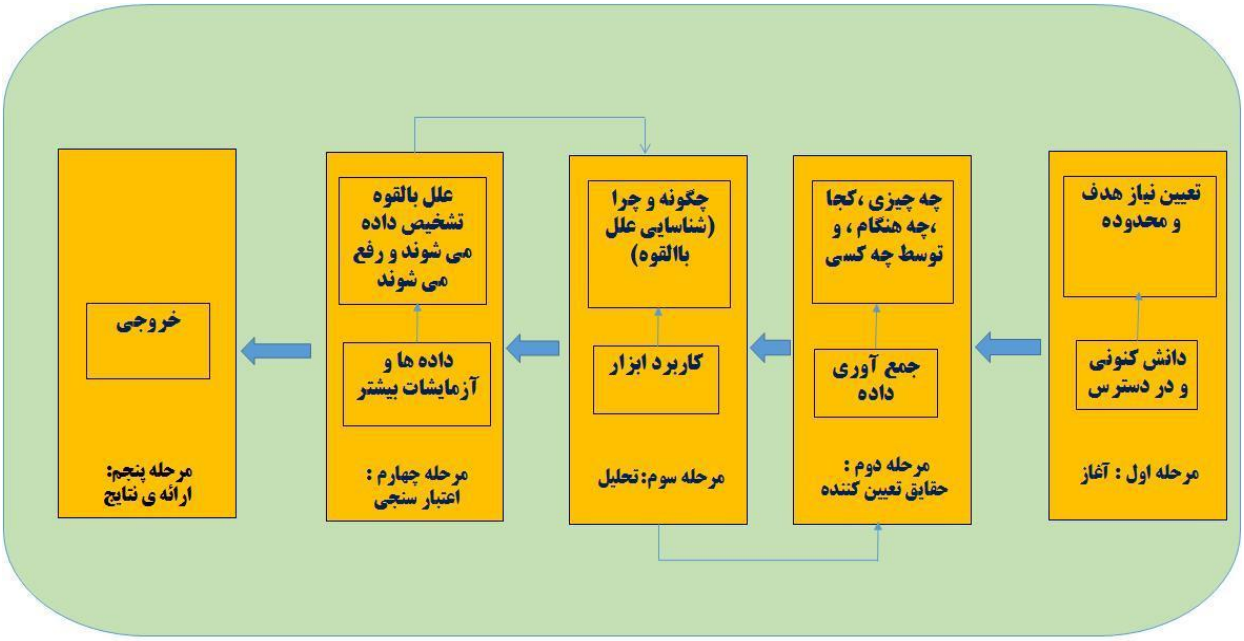

شکل ۱: مراحل فرآیند تحلیل علل ریشه‌ای

۴-۱- مرحله آغاز (Initiation)

۴-۱-۱- این مرحله شامل موارد ذیل می‌باشد:

- نیازسنجی انجام تحلیل
- تعریف دامنه و هدف تحلیل (با توجه به رویداد مورد نظر)
- تعیین کارگروه و منابع

۴-۱-۲ معیارهای نیازسنجی (معیارهای آستانه ای) بر اساس رویکردهای ذیل تعیین می‌شود:

- بررسی دوره ای سوابق نگهداشت (تعیین تجهیزات با بیشترین خرابی یا خرابی‌های با بیشترین تکرار)
- ارزیابی روند تغییرات (مثبت/منفی) شاخص‌های کلیدی عملکرد و تحلیل آنها(برای مثال MTBF، OEE، Availability و ...)
- خرابی منجر به هرگونه رویداد با پیامدهای ایمنی(فوت/نقص عضو / از کارافتادگی و ...)
- خرابی منجر به هرگونه رویداد با پیامدهای زیست محیطی(الزامات قانونی)
- عدم تطابق منجر به هرگونه رویداد با پیامدهای هزینه‌ای تعمیرات/بازسازی/نوسازی دارایی های فیزیکی
- عدم تطابق منجر به هرگونه رویداد با پیامد عدم النفع در زنجیره تامین

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۴-۲- مرحله تعیین حقایق/وقایع

۴-۲-۱- مرحله تعیین حقایق/وقایع بعنوان مهمترین بخش فرآیند، شـــامل اقدامات لازم برای آماده ســـازی تحلیل و موارد ذیل می‌باشد:

- وقایع بر مبنای چه اتفاقی، کجا، چه زمانی و توسط چه کسی رخ داده است تعیین می‌شود.
- اطلاعات و داده ها باید قبل از آنکه از دست برود جمع‌آوری شود.

۴-۲-۲- در جمع‌آوری داده ها موارد ذیل مورد توجه قرار گیرد:

- زمینه ای که در آن رویداد مورد نظر رخ می‌دهد.
- شرایط قبل، در طول و بعد از رویداد مورد نظر
- مشارکت پرسنل از جمله اقدامات صورت گرفته و نگرفته و تصمیم‌گیری‌ها
- داده‌هایی در مورد محیط اطراف
- چگونگی عملکرد سازمان از جمله :نمودار سازمانی، فرآیندها و مراحل آموزش و مهارت
- داده‌های تاریخی مرتبط با رویداد ها
- انحراف از آن چیزی که مورد انتظار است.
- تعاملات با دیگر آیتم ها و پرسنل
- تجهیزات مشارکت کننده،حالت راه اندازی آن‌ها و انطباق آن‌ها با احتیاجات

۴-۲-۳- شواهد مورد نیاز برای انجام تحلیل به سه گروه تقسیم می‌گردد:

۴-۲-۳- ۱- شواهد فیزیکی

شواهد فیزیکی که لازم است برای ریشه‌یابی رویداد مورد بررسی قرار گیرد عبارتند از :

- بررسی وضعیت ظاهری محل رویداد (برای مثال در ارتباط با وقوع خرابی تجهیزات، مکانیزم خرابی قطعه آسیب دیده و مقایسه آن با نمونه سالم قطعه مورد نظر، شرایط فیزیکی محل وقوع رویداد)
- بررسی وضعیت گریس، روغن و ... . (بعنوان مثال ممکن است نیاز باشد تا آنالیز روغن و گریس برای بررسی علت خرابی چرخ دنده یا بیرینگ خاص نیاز باشد)
- بررسی وضعیت ظاهری محل آسیب دیده بر روی تجهیز جهت ردیابی هرگونه وضعیت غیرعادی اثرگذار در وقوع عیب

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۴-۲-۳-۲- شواهد انسانی

جهت بررسی ارتباط و میزان تاثیر پرسنل در وقوع عیب و همچنین کسب آگاهی بیشتر از مکانیزم وقوع خرابی و نشانه‌هایی که در هنگام وقوع عیب توسط پرسنل مشاهده شده لازم است تا مذاکراتی با پرسنل مشروحه زیر انجام پذیرد :

- اپراتور بهره بردار در شیفت مرتبط با زمان وقوع رویداد
- تعمیرکار داخلی (از تأسیسات یا تعمیرات اساسی) یا پیمانکار که مجری تعمیرات بوده است
- نظرات پرسنل پایش وضعیت (CBM) در ارتباط با وضعیت تجهیز
- توضیحات سایر شاهدان رویداد

۴-۲-۳- ۳-شواهد اسنادی

شواهد اسنادی برای ارزیابی روند وقوع رویداد مورد استفاده قرار گرفته و تکمیل کننده نظرات کارشناسان تیم تحلیل می‌باشد. این شواهد عبارتند از :

- سوابق بهره‌برداری
- برنامه و سوابق نگهداشت (تعمیرات / بازرسی فنی)
- دستورالعمل‌های بهره‌برداری
- نقشه‌های محل آسیب دیده

۴-۲-۳- ۴- نمونه هایی از شواهد

- بازرسی از شواهد فیزیکی مانند قطعات معیوب و گزارش‌های نامطلوب
- عکس و فیلم هایی که توسط دوربین‌های نظارت گرفته می‌شود.
- داده‌های عملیاتی توسط سیستم‌های نظارت، سیستم‌های کنترل و گزارش‌های اپراتورها
- گواهی فردی با انجام مصاحبه ها
- شواهد مستند از رویه‌های مرتب، عملیات محیطی

هنگامی که تمام اطلاعات مرتبط با رویداد مورد نظر جمع‌آوری شد، داده‌ها باید به منظور صحت و تناسب بررسی شوند.داده‌های از دست رفته باید یافت شوند و هرگونه تناقض برای اطمینان رفع شود تا یک تصویر روشن و سازگار از رویداد مورد نظر تعیین شود.

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۴-۳- مرحله تحلیل رویداد

۴-۳-۱-هدف از این مرحله درک رویداد مورد نظر و علل آن می‌باشد که شامل موارد ذیل می‌باشد:

- مشخص کردن چگونگی و چرایی وقوع رویداد
- سازمان دهی داده‌ها و جمع‌آوری داده‌ها در یک فرم استاندارد
- بررسی واقعیت‌ها، به منظور شناسایی دلایل وقوع رویداد بعنوان عوامل علّی لازم
- پیشنهاد یک یا چند فرضیه بعنوان علت و عوامل موثر و شرایط حاکم در جاهایی که حقایق کافی نباشد.

۴-۳-۲-در جاهایی که حقایق لازم در دسترس نباشد، تحلیل شامل موارد زیر است:

- سازماندهی شواهد فیزیکی و اظهارات شاهد در مورد اقدامات، حوادث، شرایط و نتایج
- جستجوی چگونگی و چرایی وقوع رویدادهای مورد نظر با استفاده از اطلاعات جمع آوری شده، به منظور قضاوت نتایج، مدل‌های علّیت، تست‌های آزمایشگاهی، چک‌لیست‌ها و طبقه بندی ها یا تحلیل آماری داده‌ها، برای کمک به این روند مورد استفاده قرار می‌گیرد.
- نگاهی فراتر به عوامل علّی فوری برای یافتن دلیل رخداد آن‌ها و یافتن تمام عوامل علّی و نه فقط علل آشکار روند تحلیل تا زمانی ادامه دارد که قاعده توقف فراخوانده می‌شود.

به طور کلی عوامل علّی شامل مسائل فنی، جنبه‌های انسانی، عوامل مرتبط با محیط فیزیکی و یا روانی – اجتماعی می‌باشد.

۴-۳-۳-ویژگی‌های اعضای تیم تحلیل

تحلیل علل ریشه‌ای می‌تواند حداقل توسط یک نفر با تجربه و کارشناس، مسلط بر تکنیک تحلیل علّی انجام شود. لیکن انجام تحلیل علل ریشه‌ای به صورت گروهی رایج است و اعضای تیم تحلیل بر اساس مهارت‌های مورد نیاز انتخاب می‌شوند.

۴-۳-۳-۱- اهم ویژگی‌های اعضای تیم تحلیل به شرح ذیل است:

- باید فرد یا افرادی که بتوانند یک دید کلی از سیستم‌ها و آگاهی از برنامه یا پروژه و رویداد مورد نظر فراهم کند برای عضویت در تیم تحلیل انتخاب شوند.
- باید یک تسهیل گر ماهر در تکنیک تحلیل علّی که به نحوی مطلوب، آموزش دیده یا در تسهیل روش تجزیه و تحلیل علّی و با تجربه در تیم تحلیل باشد.
- اعضای تیم تحلیل می‌توانند بسته به نوع فعالیتی که انجام می دهند تغییر کند.
- اعضای تیم تحلیل می‌توانند شامل مهندسان، تکنسین‌ها، اپراتورها، نمایندگان فروش و مدیران باشند.

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- استفاده از ظرفیت‌های/منابع خارج از سازمان باید جهت ارایه دیدگاه مستقل در نظرگرفته شوند.
- نقش اعضای تیم تحلیل باید برای فعالیت های خاص در طول تحقیقات، به ایجاد تخصص در تیم و افزایش تاثیر کمک نماید.

۴-۴- انواع مدل‌های تحلیل ریشه‌ای

الف- مدل تحلیل مانع (Barrier Analysis)

ب- مدل ریزن (مدل پنیر سوییسی) (Reason's Model)

پ- مدل سیستم (System's Model)

ت- مدل و فرآیندهای حادثه تئوریک سیستم‌ها (STAMP)

الف- مدل تحلیل مانع (Barrier Analysis)

بر این فرضیه استوار است که رویداد مورد نظر به عنوان نتیجه ای از فعل و انفعال منبع آسیب زننده بر روی یک هدف، رخ می‌دهد و این می‌تواند با استفاده از موانع بازدارنده، پیشگیری شود. یک رویداد نامطلوب، زمانی رخ می‌دهد که این موانع از دست بروند، خراب شوند یا ناموثر واقع شوند.

نقاط قوت :

شناسایی آن دسته از اقدامات اصلاحی که به منظور حصول اطمینان از اینکه موانع مناسب هستند (تعداد و اثر بخشی) مورد نیاز است.

محدودیت‌ها:

- ممکن است تمام موانع از دست رفته یا خراب شده را شناسایی نکند یا اثر تناوب را بر اینکه چه موانعی دچار مشکل شده‌اند مشخص نکند.
- عوامل علّی فوری را می یابد تا اینکه علل ریشه‌ای را کشف کند، اما چرایی این مسئله را در هیچ سطحی، بررسی نمی‌کند.

ب-مدل ریزن یا مدل پنیر سوییسی (Reason's Model)

این مدل مبتنی بر این فرض منطقی است که عناصر اساسی مورد نیاز سیستم بهره‌ور، شامل موارد زیر است:

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- تصمیمات مناسب مدیریت شرکت و کارخانه
- اقدامات خطی مدیریت، آموزش عملیات نگهداشت و غیره
- قابلیت اطمینان و تناسب برای استفاده از ابزار
- نیروی کار با انگیزه
- یکپارچگی عناصر مکانیکی و انسانی
- تدابیر امنیتی در برابر ریسک‌های قابل پیش بینی
- نقاط ضعف در عناصر سیستم بهره‌ور، به عنوان حفره‌هایی از تکه‌های پنیر سوییسی به تصویر کشیده می‌شوند. یک رویداد، زمانی حاصل می‌شود که تمام نقاط ضعف در یک مسیر قرار بگیرند.

نقاط قوت:

این مدل تحلیل گر را حمایت می‌کند تا عوامل علّی خطای اپراتور را کشف کند و از این رو آن را کاهش می‌دهد.

محدودیت‌ها:

- تحلیل سطحی از عوامل علّی محیطی یا فنی، که جوانب فنی را تنها به عنوان موانع از دست رفته در نظر می‌گیرد.
- فرض می‌کند که مشکل اصلی، خطای انسانی است.
- طبقه بندی را برای کمک به شناسایی انگیزه ها و اهداف روانی خطای انسانی یا شناسایی خرابی های پنهان، فراهم نمی‌کند و از این رو به مهارت‌هایی در روانشناسی فردی و سازمانی نیاز هست.

پ- مدل سیستم (System's Model)

تئوری سیستم در ده های ۱۹۴۰ و ۱۹۵۰ برای کنترل افزایش پیچیدگی در سیستم‌ها بعد از جنگ جهانی دوم و برای در نظر گرفتن جوانب فنی و اجتماعی سیستم‌ها بطور موازی، بعنوان یک مجموعه مطرح شد. در این مدل فرض شده است که تعامل انسان با فناوری در ساختارهای پیچیده اجتماعی، تحت تاثیر اهداف، خط مشی، فرهنگ سازمان، اقتصاد داخلی و خارجی، عناصر قانونی، سیاسی و محیطی است. این سیستم با سرعت زیاد تغییرات فناوری یک محیط که به صورت افزایشی و رقابتی است، مورد بررسی قرار می‌دهد.

روش‌های مبتنی بر این سیستم در جستجوی یک زنجیره علّی یا خطای فردی یا خرابی‌های فنی نیست، بلکه سیستم را بطور کلی با تعاملات و نقاط ضعف آن در نظر می‌گیرد. یک خطای انسانی یا خرابی سخت افزاری، ممکن است شناسایی شود اما تمرکز روی تعاملات و مسائل سیستمی است.

ت- مدل و فرآیندهای حادثه تئوریک سیستم‌ها (STAMP)

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روش STAMP یک مدل با رویکرد علّی مبتنی بر تئوری سیستم‌ها است که مدل سنتی را گسترش داده است تا عوامل همکار اجتماعی و فنی در رویدادها و ارتباطات آنها را شناسایی کند. این روش همچنین تعاملات کمک کننده بین اجزا و فرآیندهای سیستم‌های سالم، ساز و کارهای علّی و سیستمی و غیرمستقیم، تصمیم گیری های پیچیده مدیریتی و اپراتور، فناوری های پیشرفته از قبیل سیستم‌های دیجیتال و نرم افزاری و نقص های طراحی سیستم را در رویدادها جستجو می‌کند. در این روش فرض می‌شود که وقایع از تعاملات بین انسان‌ها، دستگاه‌ها و محیط بوجود می‌آید. این روش شامل این مفهوم است که وقایع اغلب از یک حرکت آهسته در تمام سیستم به وضعیتی با ریسک بالا منجر می‌شود بگونه‌ای که فشار های مالی و فشارهای دیگر که منجر به تغییر رفتار در طول زمان می‌شوند، می‌توانند در فرآیند تحلیل علّی در نظر گرفته شوند.

نقاط قوت:

- نقش کل سیستم فنی و انسانی را در علّیت در نظر می‌گیرد.
- عوامل سیستمی و غیر مستقیم را در تفسیر علّی در نظر می‌گیرد.
- مدلی را برای توضیح پیشامد ها در سیستم‌های پیچیده، فراهم می‌کند.
- علت‌هایی که به فرآیند برمیگردند و یک سیستم با آنها توسعه یافته است را شناسایی می‌کند.

توجه: برای انتخاب مدل مناسب جهت تحلیل علل ریشه‌ای رویداد می‌توانید به پیوست اطلاعی مدل‌های تحلیل ریشه‌ای رویداد (Annex B) مراجعه نمایید.

۴-۵- انواع تکنیک‌های تحلیل علل ریشه‌ای

تکنیک‌ها به منظور کمک به تحلیلگران در شناسایی عوامل عللی و در نهایت علل ریشه‌ای طراحی شده‌اند.

در جدول شماره ۲ برخی از تکنیک‌های پر کاربرد آمده است. شایان ذکر است انتخاب تکنیک مناسب بر اساس نوع کسب و کار، رویداد، سطح بلوغ سازمان، تخصص و درجه مهارت تعیین می‌گردد.

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جدول ۲: فهرستی از انواع تکنیک‌های تحلیل علل ریشه‌ای رویداد

ردیف	تکنیک‌های تحلیل علل ریشه‌ای	شرح تکنیک
۱	نمودار رو یداد ها و عوا مل علّی (ECF)	توالی زمان یک سری از وظایف و یا اقدامات شرایط پیرامون را که منجر به رویداد می‌شود در یک دیاگرام علّی معلولی شناسایی می‌کند.
۲	روش چرا – چرا (Why-Why)	این روش تحلیل را از طریق زنجیره علّی با چندین بار پرسش چرا انجام می‌دهد.
۳	روش درخت علت(CTM)	یک تکنیک سیستماتیک برای تحلیل و به تصویر کشیدن گرافیکی رویدادها و شرایط مربوط به رویداد مورد نظر است.
۴	دیاگرام ایشیکاوا یا استخوان ماهی (Fish Bone)	یک تکنیک است که به شناسایی، تحلیل و ارایه علت‌های ممکن رویداد کمک می‌کند.
۵	روش درخت خطا (FTA)	درخت خطا یا موفقیت یک نمایش گرافیکی از اطلاعات، برای کمک به کاربر در تحلیل استقرایی برای تعیین مسیر های مهم جهت موفقیت یا خرابی که به صورت گرافیکی در یک دیاگرام درخت منطقی نمایش می‌شود.
۶	توالی رویدادهای چند خطی (MES) و طرح رویدادهای زمان بندی شده متوالی (STEP)	(MES) و (STEP) روش‌هایی از جمع آوری داده و پیگیری جهت تحلیل رویدادهای پیچیده هستند و نتایج بعنوان یک ماتریس زمانی از رویدادها را نشان می‌دهد.
۷	تحلیل چرا – زیرا (WBA)	شبکه ای از عوامل علّی مسئول برای رویداد است که با استفاده از مقایسه دوعاملی، آزمون خلاف ایجاد می‌کند. شبکه عوامل در یک گراف چرا – زیرا نمایش داده می‌شود.
۸	ایمنی از طریق یادگیری سازمانی(SOL)	یک ابزار تحلیل با محوریت چک لیست است که برای رویدادهای مورد نظر در ایستگاه‌های انرژی هسته ای به کار می رود. نتایج به شکل دیاگرام با محوریت زمان هستند.
۹	مدیریت نظارت و درخت ریسک (MORT)	نمودار (MORT) یک درخت عیب از پیش تعیین شده از رویدادها ست که معمولا عیب ها و اشتباهات به صورت کلی در آن بیان می‌شوند. این درخت شامل دو شاخه اصلی و تعدادی زیر شاخه

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ردیف	تکنیک‌های تحلیل علل ریشه‌ای	شرح تکنیک
		هست. شاخه های اصلی عوامل ویژه کنترل، سیستم‌های مدیریت و اطلاعاتی را شناسایی می‌کند.
۱۰	نقشه‌های استاندارد (Accimaps)	یک تکنیک برای نمایش تحلیل علّی می‌باشد و نیازمند یک مدل سازمانی برای تفکیک عوامل به لایه ها و استخراج عوامل از لایه هاست.
۱۱	بتا سه رکنی (Tripod beta)	ارایه یک دیاگرام درختی از شبکه ی علّی با تمرکز بر عوامل انسانی است.و در جستجوی خرابی‌هایی در سازمان است که می‌تواند منجر به خطای انسانی شود.
۱۲	تحلیل علّی برای مدل و فرآیند سیستم‌های نظری پیشامد (STAMP) و (CAST)	(CAST) تکنیکی است که تمام فرآیند اجتماعی – فنی درگیر در رویداد را مورد آزمون قرار می‌دهد.

توجه: برای انتخاب تکنیک مناسب جهت تحلیل علل ریشه‌ای رویداد می‌توانید به پیوست اطلاعی تکنیک‌های تحلیل ریشه‌ای رویداد (Annex C) مراجعه نمایید.

۴-۶- مرحله تایید

هدف از این مرحله تصدیق نتایج مرحله تحلیل است که شامل موارد ذیل می‌باشد.

- تعدادی از فعالیت‌های بررسی شده در سراسر فرآیند تحلیل علت ریشه‌ای اجرا شده‌اند تا تعیین کنند که آیا داده‌های جمع‌آوری شده مرتب هستند و تحلیل نمایشگر داده‌های جمع‌آوری شده است ؟
- این مرحله بررسی میکند که آیا علل شناسایی شده در تحلیل می‌تواند اثبات شود.-
- یک بررسی مستقل است، به منظور اینکه آیا تحلیل کامل و صحیح است.
- حصول اطمینان از دستیابی به اهداف مرحله تحلیل
- روش بررسی، به روش تحلیل شده و رویداد مورد نظر بستگی دارد.
- آزمایشات می‌تواند برای تکرار وقوع رویداد مورد نظر انجام شود.
- از روش‌های آماری برای ارزیابی میزان تایید فرضیه‌ی علت استفاده می‌شود.
- از شبیه‌سازی برای تایید علت‌ها استفاده می‌شود.

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۴-۷- مرحله ارائه نتایج

نتایج تحلیل به هدف تحلیل بستگی دارد. اگر هدف تحلیل، شناسایی اقدامات برای جلوگیری از رخداد رویداد مشابه باشد، نتایج تحلیل، شناسایی اقدامات اصلاحی است. اگر هدف تحلیل، تکرار موفقیت است، نتایج شامل اقدامات برای افزایش احتمال تکرار رویدادو پیامدهای مورد نظرمی‌باشد.

اثر بخشی نتایج تحلیل به کیفیت تحلیل بستگی دارد. می‌بایست یک قالب مورد توافق برای ارایه نتایج تحلیل علل ریشه‌ای ایجاد شود. نتایج گزارش اقدامات، باید حداقل شامل موارد زیر باشد:

- توصیف کلی برای هر علت که نیاز به اقدام دارد با اطلاعات و جزئیات کامل
- مجموعه‌ای از جایگزین ها برای اقدامات رفتاری و خلاصه ای از مزایا و هزینه‌های هر کدام در محدوده دامنه
- اقدامات توصیه شده برای رسیدگی به هر یک از علل شناخته شده و بررسی اقدامات از منظر اثر بخشی و واقع گرایی
- اقدامات اصلاحی برای دستیابی به اهداف تغییر احتمال رویداد مورد نظر و یا پیامدهای آن و همچنین تحمیل نکردن ریسک‌های غیر قابل قبول جدید.

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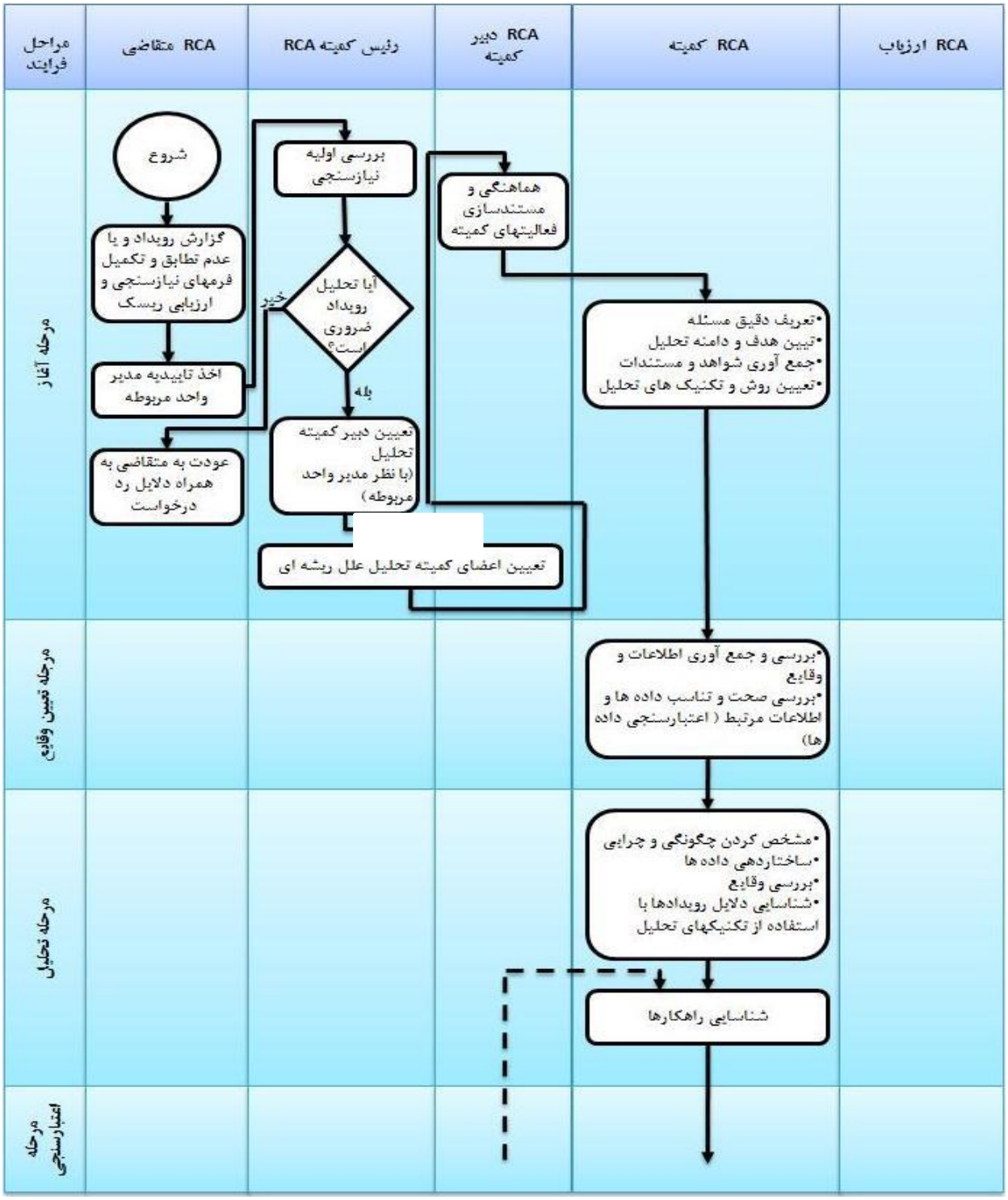
۴-۸- گردش کار فرایند (RCA) :



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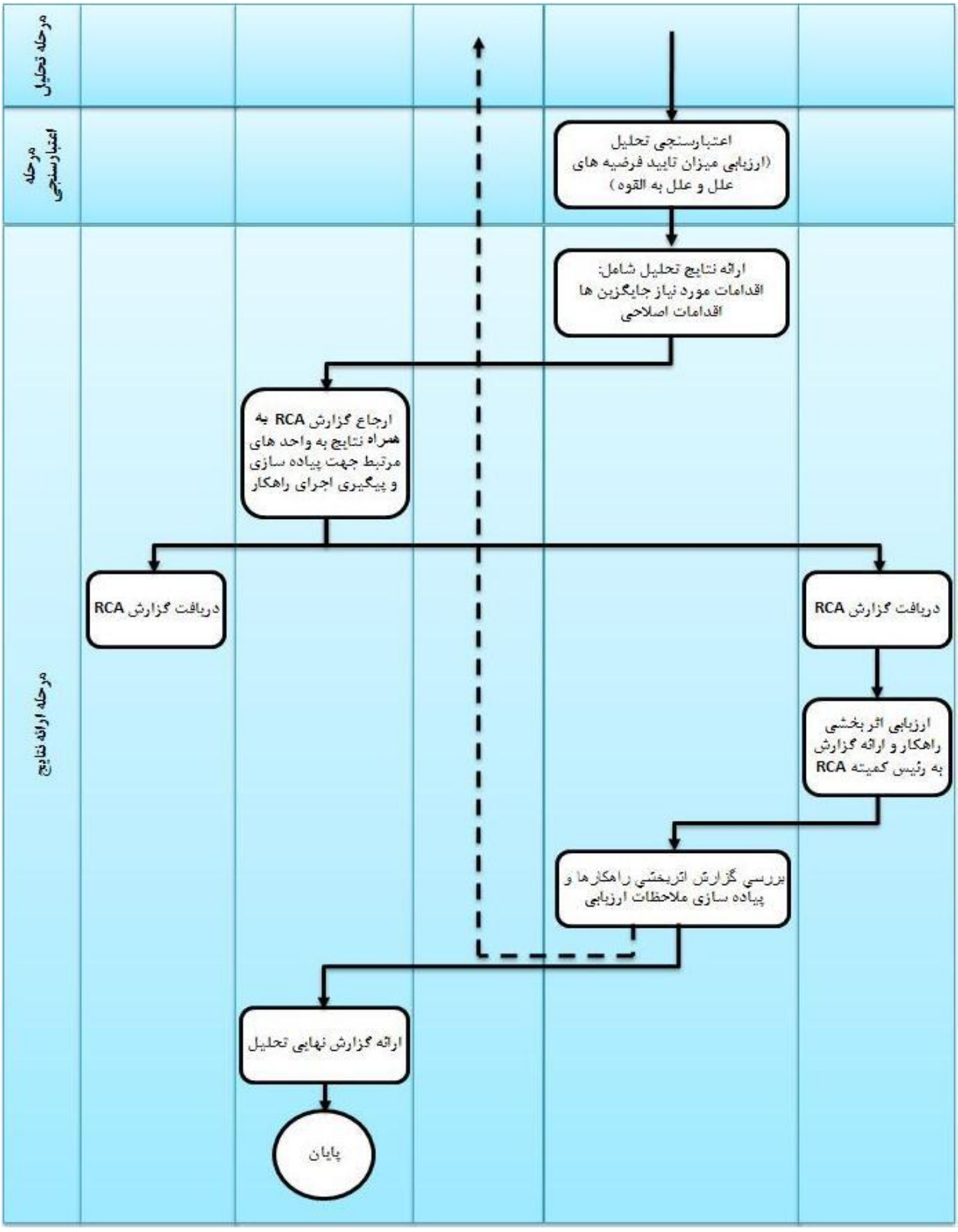

شکل ۲: گردش کار و توصیف فرآیند تحلیل علل ریشه‌ای

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۴-۹- توصیف فرآیند تحلیل علل ریشه‌ای (RCA) :

جدول ۳: توصیف فرآیند تحلیل علل ریشه‌ای (RCA)

ردیف	شرح فعالیت	مسئولیت	ارجاعات
۱	تهیه گزارش رویداد و تکمیل فرم تعریف رویداد و نیاز سنجی تو سط متقا ضی انجام تحلیل صورت می‌گیرد. این ا سناد شامل اطلاعاتی اولیه از جمله شرح شـرایط عملیات در پس زمینه وقوع رویداد، فهرسـت افراد مطلع و فهرسـت منابع اطلاعاتی مرتبط اسـت. متقاضـی تحلیل می‌تواند از هرکدام از واحدهای بهره‌برداری، تعمیرات، مهندسی، HSE و غیره باشد.	متقاضی RCA	فرم تعریف رویداد و نیازسنجی
۲	متقاضی RCA باید تائیدیه رییس مستقیم/ مدیر خود برای درخواست اخذ و به رئیس کمیته RCA ارسال نماید.	متقاضی RCA	
۳	رئیس کمیته RCA پس از دریافت فرم تعریف رویداد و نیازسـنجی پس از ارزیابی اطلاعات اولیه مندرج در فرم بر اساس معیارهای آستانه‌ای و اولویت‌ها، تعیین سـطح (منطقه /شـرکت فرعی / شـرکت اصـلی) و مجوز انجام تحلیل صـادر می نماید. درصـورت تشـخیص، مبنی بر عدم نیاز به انجام تحلیل بر اساس معیارها، فرم تعریف مساله همراه با ذکر دلایل لغو درخواست، به (واحد) متقاضـی عودت می‌شـود. (عدم نیاز به تحلیل معمولاً براسـاس تکراری بودن درخواست و یا بحرانی نبودن عیب مورد درخواست تعیین می شود). درصورت ناقص بودن اطلاعات فرم، هماهنگی‌ها با متقاضـی جهت تکمیل اطلاعات فرم انجام می‌پذیرد.	رئیس کمیته RCA	
۴	هماهنگی و مسـتندسـازی فعالیت‌های کمیته برعهده دبیر کمیته تحلیل می‌باشد.	دبیر کمیته RCA	
۵	انتخاب اعضای کمیته تحلیل علل ریشه‌ای بطور مشترک توسط رئیس کمیته RCA انجام می شود. بطور کلی اعضای این کمیته باید شامل مهمترین افراد مطلع، ذینفع و تاثیر گذار بر رفع عدم تطابق را شـامل شـود که البته باید بـ صورت متوازن شامل سطوح و ق سمت‌های مختلف شود. با ت شکیل هیات تحلیل علل ریشـه، آموزش مورد نیاز جهت آشـنایی با روش تحلیل نیز برگزار	رییس کمیته RCA	

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ردیف	شرح فعالیت	مسئولیت	ارجاعات
	می شود. همچنین در سایر مراحل تحلیل در صورت نیاز امکان ا ضافه شدن افرادی به این لیست وجود دارد.		
۶	اعضاء تیم تحلیل در گام اول باید نسبت به جمع‌آوری شواهد مربوط به رویداد اقدام نمایند. لازم ا ست شواهد در سه گروه شواهد فیزیکی، شواهد انسانی و شواهد ا سنادی گردآوری گردد. ت سهیل‌گری فرآیند بر عهده یکی از اع ضای آموزش دیدهٔ کمیته RCA می‌باشد و مسئولیت اجرایی تحلیل بر عهده ایشان می‌باشد.	تسهیل‌گر و سایر کمیته RCA	فرم شواهد و انتخاب مدل / تکنیک تحلیل
۷	پس از جمع‌آوری شواهد، کار ارزیابی شواهد بدست آمده در جلسات تیم تحلیل انجام و نتایج حاصله در فرم شواهد مورد نیاز برای تحلیل درج می‌گردد. هدف در این بخش د ستیابی به تو ضیح کامل و وا ضح از روند وقوع رویداد می‌باشد.	اعضاء کمیته RCA	فرم شواهد و انتخاب مدل / تکنیک تحلیل
۸	پس از ارزیابی شواهد و ک سب شناخت کافی از ماهیت رویداد، لازم ا ست تا نسبت به انتخاب مدل و روش منا سب جهت تحلیل اقدام گردد. انتخاب روش تحلیل توسط اعضاء کمیته RCA و با هدایت تسهیل گر انجام می پذیرد.	اعضاء کمیته RCA	فرم شواهد و انتخاب مدل / تکنیک تحلیل
۹	کار تحلیل براساس روش انتخاب شده و به کمک شواهد گردآوری شده انجام می‌گردد .	اعضاء کمیته RCA	فرم شواهد و انتخاب مدل / تکنیک تحلیل
۱۰	اعضاء کمیته RCA برای علل ریشه‌ای شناسایی شده، راهکارهای جلوگیری از تکرار مجدد عیب را تعیین نموده و اطلاعات مربوطه را به همراه م شخ صات اجرای راهکارها در فرم ارایه راهکارهای پیشنهادی درج نماید.	اعضاء کمیته RCA	فرم اجرای راهکارهای پیشنهادی

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ردیف	شرح فعالیت	مسئولیت	ارجاعات
۱۱	راهکارهای پیشنهادی توسط کمیته RCA مورد ارزیابی نهایی قرار می‌گیرد	کمیته RCA	فرم اجرای راهکارهای پیشنهادی
۱۲	نتایج تحلیل شامل اقدامات مورد نیاز، جایگزین‌ها، اقدامات اصلاحی، تعیین مسئول پیگیری، دوره‌های زمانی گزارش و ضعیت، تعیین ارزیاب و دوره‌های زمانی ارزیابی در فرم مربوطه جمع بندی شده می‌شود. انتخاب ارزیاب متناسب با موضوع تحلیل توسط کمیته RCA تعیین می‌گردد. تاریخ ارزیابی معمولا در فاصله زمانی شش ماه الی یک سال از اتمام اجرای راهکارها تعیین می‌شود.	کمیته RCA	فرم اجرای راهکارهای پیشنهادی
۱۳	رییس کمیته RCA جهت پیاده سازی راهکارها نتایج تحلیل را به واحدهای مرتبط ارسال می‌گردد. ضمناً یک نسخه از نتایج به واحد متقاضی وارزیاب RCA ارجاع می‌گردد.	**رییس کمیته** RCA	فرم اجرای راهکارهای پیشنهادی
۱۴	در موعد زمانی تعیین شده، ارزیاب RCA ، پس از انجام ارزیابی، نتایج اثر بخشی حاصله و میزان صرفه جویی را به کمیته گزارش می نماید.	ارزیاب RCA	فرم گزارش ارزیابی اثربخشی
۱۵	گزارش ارزیابی جهت بررسی اثربخشی راهکارها در کمیته بررسی شده و تصمیم لازم در خصوص بازنگری در تحلیل و اجرا اتخاذ می‌گردد.	کمیته RCA	
۱۶	پایان فرآیند : گزارش نهایی تحلیل RCA برای مسئولین مرتبط ارسال می‌گردد.	رئیس کمیته RCA	گزارش نهایی تحلیل RCA

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توجه: گردش کار و توصیف فرآیند تحلیل علل ریشه‌ای (RCA)در بندهای ۴-۶ و ۴-۷ برای سازماندهی و اجرای مراحل اصلی فرایند تحلیل علل ریشه ای تدوین شده است و شرکت ها می توانند با رعایت الزامات، بر اساس مدل فرایند های کسب و کار خود این الگوریتم را متناسب سازی نمایند.

۴-۹-۱- ورودی فرآیند

ورودی های فرآیند شامل انتخاب رویداد برای تحلیل و تکمیل فرم «گزارش عدم تطابق جهت تحلیل علل ریشه‌ای» و تعیین درجه بحرانی بودن ریسک رویداد است. تعیین معیارهای آستانه‌ای برای نیازسنجی تحلیل علل ریشه‌ای بر اساس ارزیابی پیامدها و معیارهای ریسک از طریق روش‌های مرسوم (نظیر FMEA) تعیین گردد.

۴-۹-۲- معیارهای اصلی لزوم انجام تحلیل:

- هرگونه رویداد با اثری بزرگ
- چندین رویداد مشابه نامطلوب
- پارامتری که از سطح محدوده ی تعریف شده (انحراف از معیار)، خارج می‌شود
- خرابی ها و یا موفقیت هایی شامل آیتم های مهم تجهیزات یا اقدامات می‌شود

۴-۹-۳- انتخاب رویداد برای تحلیل می‌تواند از سه طریق انجام پذیرد:

۴-۹-۳-۱- روش اول: بررسی دوره‌ای سوابق تعمیرات.

در این حالت، سوابق تعمیر تجهیزات بصورت سالانه و براساس مکانیزم تصمیم‌گیری مرتبط با پیامدهای وقوع رویداد، اولویت‌بندی شده و سوابق نیازمند تحلیل مشخص می‌شود. استفاده از شاخص های توصیه شده در استاندارد IGS-O-MN-002 پیشنهاد می‌گردد.

۴-۹-۳-۲- روش دوم: ارزیابی شاخص‌های کلیدی عملکرد

روند تغییر شاخصهای کلیدی عملکرد مانند MTBF (میانگین فاصله زمانی بین خرابی تجهیزات)، Availability (قابلیت دسترسی تجهیزات) و سایر شاخص‌های عملکردی، در راستای اهداف استراتژیک، در فواصل زمانی مشخص، مورد ارزیابی قرار گیرد.

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۴-۹-۳-۳- روش سوم: گزارش مستقیم عدم تطابق

شرکت ها باید نسبت به تکمیل فرم گزارش عدم تطابق رویدادها با پیامدهای ذیل اقدام نمایند. در صورت رخ دادن حادثه لازم است فرم گزارش حادثه ضمیمه فرم گزارش عدم تطابق گردد:

- عدم تطابق منجر به هرگونه آسیب دیدگی (یا فوت) پرسنل شرکت که باعث عدم توانایی حضور در محل کار شود.
- عدم انطباق منجر به هرگونه نقض الزامات محیط زیستی

عدم انطباق منجر به ایجاد هزینه بابت اتلاف انرژی، توقف غیرمجاز عملیات، تعمیرات، شکایت مشتری، تناوب بروز خرابی یا نقض هرگونه الزامات دیگر؛ که برای هرکدام از این موارد هزینه‌ای فوق، انجام آنالیز تخمینی سود – هزینه (شامل اجرای خود تحلیل ریشه‌ای و راهکارهای خروجی اش) جهت تایید شروع تحلیل لازم است.

سایر موارد دیگری که به هردلیلی شامل سه‌دسته پیامدهای ذکر شده در بالا نباشند نیز با نظر موافق مدیر مربوطه و کمیته RCA بصورت موردی ممکن است. (بعنوان مثال ریسک قریب الوقوعی که هنوز منجر به وقوع عدم تطابق و پیامد منفی نشده است؛ و یا رویدادی که منجر به پیامدهای شدید نشده ولی در صورتی که مختصری شرایط متفاوت می‌بود می‌توانست پیامدهای جدی در پی داشته باشد.

۴-۹-۴- ویژگی‌های اعضای کمیته تحلیل علل ریشه‌ای رویدادها

اعضای کمیته تحلیل براساس سطح تحلیل، نوع رویداد و تخصص‌ها و مهارت‌های لازم انتخاب می‌شوند. کمیته باید دارای ویژگی‌های ذیل باشد:

- حداقل یکی از اعضای کمیته تحلیل بایستی دید جامع و آگاهی کامل از پروژه و رویداد اصلی را ارایه نماید.
- تسهیل گر کمیته می‌بایست مهارت لازم در تکنیک‌های تحلیل علل ریشه‌ای را از طریق تجربه و یا آموزش اخذ نموده باشد.
- اعضای کمیته تحلیل می‌توانند بسته به نوع فعالیتی که انجام می دهند تغییر کند.
- اعضای کمیته تحلیل می‌توانند شامل مهندسان، تکنسین‌ها، اپراتورها، نمایندگان فروش و مدیران باشند.
- به کارگیری اعضای خارج از کمیته تحلیل می‌بایست به صورتی باشد که دیدگاه مستقل کمیته حفظ شود و از مخفی شدن حقایق مرتبط رویداد اصلی، در سازمان جلوگیری شود.
- اعضای اضافی کمیته به منظور حمایت از تحقیقات و کشف علل رویداد بکار گرفته می‌شوند.

۴-۹-۵- منابع اطلاعات (مستندات / سوابق / شواهد) مورد نیاز برای تحلیل

نمونه‌های ذیل بعنوان داده‌های مورد نیاز برای جمع آوری شواهد می‌تواند مورد استفاده قرار گیرد:

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- بازرسی از شواهد فیزیکی مانند قطعات معیوب و گزارش‌های نامطلوب
- عکس و فیلم هایی که توسط دوربین‌های نظارت گرفته می‌شود.
- داده‌های عملیاتی توسط سیستم‌های نظارت، سیستم‌های کنترل و گزارش‌های اپراتورها
- گواهی فردی با انجام مصاحبه‌ها
- شواهد مستند از رویه‌های مرتبط، عملیات محیطی
- شواهد مورد نیاز برای انجام تحلیل می‌تواند به سه گروه شواهد فیزیکی، انسانی و اسنادی تقسیم شود. لازم است شواهد حفظ و نگهداری شود.

۴-۹-۶- ارزیابی اثربخشی اجرای RCA

اهدف فرآیند RCA در حذف کامل (یا کنترل) عدم تطابق از طریق جلوگیری از تکرار مجدد آن وسایر رویدادهای مشابه است. رخداد مجدد عدم تطابق نشانگر آنست که فرآیند تحلیل علل ریشه‌ای رویدادها به یکی از دلایل زیر اثربخش نبوده است:

- خطا در تعیین علل ریشه‌ای رویداد
- خطا در تعیین فعالیت‌ها برای حذف، تغییر یا کنترل علل ریشه‌ای رویداد
- خطا در تعیین پارامترها برای پایش وضعیت پیاده‌سازی راهکارها

در کنار بررسی وقوع مجدد، موارد زیر بعنوان راهنما برای ارزیابی نتایج قابل استفاده است:

- افزایش میزان سود (بازگشت سرمایه)
- افزایش ایمنی (کاهش نسبت حوادث)
- افزایش قابلیت اطمینان (شاخص MTBF)
- شاخص‌هایی که بهبود در نتایج آنها در گزارش آنالیز تخمین زده شده (و در واقع معیاری جهت توجیه و تایید پیاده‌سازی بوده‌اند)
- سایر شاخص‌های مهم عملکردی سازمان
- باتوجه به موارد فوق‌الذکر، ارزیاب RCA به کمک اطلاعات مندرج در گزارش تحلیل و سایر گزارشات حاصل از پیگیری و اجرای راهکارها به تعیین وضعیت اثربخشی پروژه مورد نظر پرداخته و در صورت وجود توصیه‌ها و ملاحظات، آنها را در گزارش ارزیابی خود به رئیس کمیته RCA بازخورد می‌دهد.
- دوره‌های زمانی ارزیابی متناسب با نوع رویداد و راهکارهای تعیین شده توسط کمیته RCA مشخص می‌گردد.
- ارزیاب می‌بایست مهارت‌های لازم را اخذ کرده باشد.
- رییس کمیته RCA، ارزیاب را تعیین می‌کند.

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۴-۹-۷- ارایه نتایج

- نتایج فرآیند RCA عبارتند از:
- گزارش تحلیل علل ریشه‌ای شامل برنامه اجرایی پیاده‌سازی راهکارها و به همراه پیوست‌های مربوطه
- سایر اسناد و احکام لازمه جهت پیاده‌سازی راهکارها (مانند دستورکار، تایید مالی و غیره)
- گزارشات پیگیری و اتمام پیاده‌سازی راهکارها برای جلوگیری از تکرار یا کنترل عدم تطابق مورد بررسی.
- گزارشات ارزیابی دوره ای

۴-۹-۸- مستندات و سوابق

فهرست کلیه فرم‌های استاندارد و اجباری طی اجرای این رویه، که در پیوست‌های ۲ و ۳ ارایه شده‌اند، در قالب جدول ذیل به همراه مدت نگهداری و نحوه تشکیل پرونده و دستیابی به آن‌ها تبیین شده است.

- فرم تعریف رویداد
- فرم‌های نیازسنجی و ارزیابی ریسک
- فرم شواهد مورد نیاز برای تحلیل
- فرم انتخاب مدل و تحلیل علل ریشه‌ای
- فرم تعیین راهکارهای پیشنهادی
- فرم وضعیت پیشرفت اجرای راهکارها و اقدامات
- فرم گزارش ارزیابی اثربخشی
- فرم گزارش نهایی تحلیل RCA

برای سایر گزارشات و مکاتبات لازمه، جهت کاهش پیچیدگی و بروکراسی، فرمت خاصی در نظر گرفته نشده و طبق روال عادی اداری نگارش، پیگیری می‌شوند.

همچنین توصیه می‌شود اسناد جدول زیر و فرآیند مدیریت تحلیل‌های علل ریشه‌ای رویدادها بصورت الکترونیکی و غیر کاغذی مدیریت شود.

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جدول ۴: نگهداری اسناد مدیریت تحلیل‌های علل ریشه‌ای رویدادها

ردیف	شماره سند	عنوان فرم/سابقه	مدت نگهداری	نحوه تشکیل پرونده	نحوه دستیابی
۱	منطبق بر کدگذاری محلی	فرم گزارش عدم تطابق جهت تحلیل علل ریشه‌ای	۱۰ سال	کامپیوتر/ زونکن سوابق تحلیل علل ریشه‌ای در دفتر کمیته RCA مجتمع/ منطقه	نام مجتمع/ واحد یا ایستگاه/ نام و کد تجهیز/ دسته‌بندی/ شماره/ تاریخ
۲	منطبق بر کدگذاری محلی	گزارش تحلیل علل ریشه‌ای	۲۰ سال		

اسناد خروجی فرآیند تحلیل علل ریشه‌ای که حداقل باید به مدت ۱۰ سال (تا تعیین تکلیف در آن زمان) توسط کمیته RCA شرکت‌ها نگهداری شوند.

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پیوست‌ها (اطلاعی)

۱- نمونه فرم‌های راهنما

- تعریف رویداد
- جمع آوری داده‌ها وشواهد
- انتخاب مدل و تحلیل علل ریشه‌ای
- تعیین راهکارهای پیشنهادی
- وضعیت پیشرفت اجرای راهکارها
- گزارش ارزیابی اثربخشی

۲- پیوست اطلاعی خلاصه و معیارهای تکنیک‌های رایج تحلیل علل ریشه‌ای رویداد

(Annex A: Informative - Summary and criteria of commonly used RCA techniques)

۳- پیوست اطلاعی مدل‌های تحلیل علل ریشه‌ای رویداد (Annex B : Informative - RCA models)

۴- پیوست اطلاعی تشریح تکنیک‌های رایج تحلیل علل ریشه‌ای رویداد

(Annex C: Informative - Detailed description of RCA techniques)

۵- پیوست اطلاعی ابزار کمکی جهت انجام تحلیل علل ریشه‌ای رویداد

(Annex D: Informative - Useful tools to assist root cause analysis)

۶- پیوست اطلاعی تجزیه و تحلیل عملکرد نیروی انسانی

(Annex E: Informative - Analysis of human performance)

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پیوست ۱

فرم تعریف رویداد

تاریخ: .....

شماره: .....

درخواست کننده	نام و نام خانوادگی	شماره پرسنلی	سمت	واحد سازمانی	شرکت/ منطقه/ ناحیه/ تاسیسات
مشخصات تجهیز / محل وقوع					
زمان وقوع رویداد	تاریخ:	ساعت و شیفت:			
شرح رویداد(عدم تطابق / عیب)					
سابقه تکرار					
وضعیت فعلی تجهیز/ فرآیند	به حالت عادی برگشته ☐ جهت رفع عدم تطابق هنوز متوقف است ☐ توضیحات:				
	زمان برگشت به حالت عادی:				
خلاصه اقدامات انجام شده					
پیامدهای رویداد(بالقوه/بالفعل)	HSE ☐ تولید ☐ هزینه☐ سایر☐ توضیحات:				
تعیین درجه ریسک	مستندات ارزیابی ریسک ضمیمه گردید ☐				
افراد مطلع و/ یا پیشنهادی جهت عضویت در کمیته تحلیل علل ریشه‌ای:					
فهرست مراجع اطلاعاتی پیشنهادی:					
درخواست شروع تحلیل علل ریشه‌ای بصورت اضطراری را ندارم ☐ دارم ☐توضیحات:					
نام/ سمت/ امضای درخواست کننده:	نام، سمت/ امضای تایید کننده		نام، سمت/ امضای تصویب کننده		

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فرم جمع آوری داده‌ها وشواهد

تاریخ: .....

شماره: .....

شواهد و داده‌ها (گزارش جمع آوری)	**فیزیکی**	
	انسانی	
	اسنادی	
شرح توالی رویداد بر اساس داده‌های استخراج شده		
اقدامات اولیه کنترلی رویداد		
اعضای کمیته RCA امضاء:		

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فرم انتخاب مدل و تکنیک تحلیل علل ریشه‌ای

تاریخ: .....

شماره: .....

مدل انتخابی تحلیل علل ریشه‌ای	☐ تحلیل مانع (**Barrier Analysis**) ☐ مدل دلیل (مدل پنیر سوییسی)(**Reason's Model**) ☐ مدل‌های سیستم (**System's Model**) ☐ مدل و فرآیندهای پیشامد تئوریک سیستم‌ها (**STAMP**)
دلایل انتخاب مدل تحلیل	
تکنیک انتخابی تحلیل علل ریشه‌ای	
دلایل انتخاب تکنیک	
اعضای کمیته RCA امضاء:	

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فرم تعیین راهکارهای پیشنهادی تاریخ: .....

شماره: .....

عنوان رویداد:							**کد رویداد:**
ردیف	**علت ریشه‌ای شناسایی شده**	**راهکار و اقدامات**	**مسئول پیگیری**	**مدت زمان انجام**	**تاریخ شروع**	**تاریخ پایان**	**ملاحظات**
دبیر کمیته: امضاء							رئیس کمیته: امضاء

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فرم وضعیت پیشرفت اجرای راهکارها تاریخ: .....

شماره: .....

عنوان رویداد:		**کد رویداد:**	
شماره فرم تعیین راهکارهای پیشنهادی:		**تاریخ پیگیری:**	
ردیف	**راهکار و اقدامات**	**وضعیت اجراء**	**ملاحظات**
مسئول پیگیری: امضاء			

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فرم گزارش ارزیابی اثربخشی

تاریخ: .....

شماره: .....

عنوان رویداد:				**شماره رویداد:**
شماره فرم تعیین راهکارهای پیشنهادی:				**تاریخ پیگیری:**
اهداف	**شاخص های ارزیابی**	**سنجه ها**	**روش محاسبه**	**کمیت متغیر**
زنجیره تامین	۱-نرخ تولید/انتقال/توزیع ۲- کاهش توقفات			
تجهیز	۱-افزایش قابلیت اطمینان ۲-افزایش دسترسی پذیری			
HSE	۱-کاهش نرخ وقوع حوادث ۲-کاهش آلودگی های محیطی ۳-کاهش آلودگی های بهداشتی			
مالی	۱- افزایش بهره‌وری ۲-افزایش درآمد			
شرح گزارش:				**نام و امضاء ارزیاب RCA**

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Annex A
(informative)

Summary and criteria of commonly used RCA techniques

A.1 General

Annex A lists the most commonly used RCA techniques, with a brief description, and provides a reference list of criteria which can be used to compare different RCA techniques. The list is not comprehensive but covers examples of the different types of techniques used.

A.2 RCA techniques

Table A.1 provides a list and brief description of the most commonly used RCA techniques.

Table A.1 – Brief description of RCA techniques

Technique	Description
Events and causal factors (ECF) charting	ECF analysis identifies the time sequence of a series of tasks and/or actions and the surrounding conditions leading to a focus event. These are displayed in a cause-effects diagram
Multilinear events sequencing (MES) and sequentially timed events plotting (STEP)	MES and STEP are methods of data-gathering and tracking for the analysis of complex focus events. The results are displayed as a time-actor matrix of events
The ‘why’ method	The ‘why’ method guides the analysis through the causal chain by asking the question why a number of times.
Causes tree method (CTM)	CTM is a systematic technique for analysing and graphically depicting the events and conditions that contributed to a focus event. CTM is similar to the 'why' method in concept, but builds a more complex tree and explicitly considers technical, organizational, human and environmental causes
Why-because analysis (WBA)	WBA establishes the network of causal factors responsible for a focus event using a two-factor comparison, the counterfactual test. The network of factors is displayed in a "why-because" graph
Fault tree and success tree method	Fault or success tree is a graphic display of information to aid the user in conducting a deductive analysis to determine critical paths to success or failure, which are displayed graphically in a logic tree diagram
Fishbone or Ishikawa diagram	The Fishbone or Ishikawa diagram is a technique that helps identify, analyse and present the possible causes of a focus event. The technique illustrates the relationship between the focus event and all the factors that may influence it
Safety through organizational learning (SOL)	SOL is a checklist-driven analysis tool, oriented towards focus events in nuclear power stations. Results are in the visual form of a time-actor diagram, derived from the MES/STEP method
Management oversight and risk tree (MORT)	The MORT chart is a pre-populated fault tree with events, usually faults or oversights, expressed in generic terms. The MORT tree contains two main branches and many sub-branches giving a high level of detail. One main branch identifies about 130 specific control factors while the other main branch identifies over 100 management system factors. The chart also contains a further 30 information system factors common to both main branches of the tree
AcciMaps	AcciMaps is primarily a technique for displaying the results of a causal analysis. It requires an organizational model to separate factors into layers and to elicit factors in the layers; applies a version of the counterfactual test (see WBA) to determine the causal relations amongst the factors
Tripod Beta	Tripod Beta is a tree diagram representation of the causal network, focusing on human factors and looking for failures in the organization that can cause human errors

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Technique	Description
Causal analysis for systems theoretic accident model and process (STAMP) (CAST)	CAST is a technique that examines the entire socio-technical process involved in a focus event. CAST documents the dynamic process leading to the focus event including the socio-technical control structure as well as the constraints that were violated at each level of the control structure

A.3 Criteria

Table A.2 provides a list and describes the criteria used to characterize the RCA techniques listed in Table A.1. Each criterion has three levels indicated by a (+), (o) or a (–), where the different levels indicate the range.

The attributes for each RCA technique using the criteria in Table A.2 are shown in Table A.3.

Table A.2 – Summary of RCA technique criteria

Criteria	Description	Levels
Expertise required	Is the method targeted towards the "sophisticated user" (does it require use of techniques such as theorem proving which requires specific expertise)? Is it suitable for use by domain experts only?	• Intuitive, little training necessary (+) • Limited training required e.g. one day (o) • Considerable training effort necessary, e.g. one week (–)
Tool support	Is tool support necessary?	• Can be well applied without dedicated tool support (+) • Tool support not required but usually needed for effective application (o) • Tool support necessary, can be applied only with dedicated tool support (–)
Scalability	Is the method scalable? Can the method be used cost effectively for simple as well as complex focus events? Can a subset of the method be applied to small, or to less-significant focus events and the full capability applied to large, or to significant focus events? So the question of scalability asks whether the complexity of analysis using the method scales with the complexity of the focus event	• Scales well with complexity (+) • Limited scalability, considerable overhead with every application (o) • Not scalable, the full method has to be applied (–)
Graphical representation	What is the nature of the method's graphical representation? The motivating principle is that a picture is better than a thousand words. It is often more comprehensible to display results of an analysis method as an image, a graph, or other form of illustration, than as purely written text. The desirable properties of a graphical representation are • to display clearly the semantics of causality (including denotation of causal factors, and taxonomy of factors), • to be cognitively (relatively) easily evaluated by a single person, • ideally, a graphical representation could also display the history of the analysis	• Graphical representation with clearly defined semantics and cognitively easy to understand (+) • Graphical representation, but without semantics (o) • No graphical representation defined (–)

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Criteria	Description	Levels
Reproducibility	Are the results of the method reproducible? Would different analysts obtain similar results for the same focus event?	• The results can be reproduced, differences are only observed on the representation of the results, wording etc. (+) • A significant amount of the results can be reproduced, but some differences will be observed (o) • The results will depend on the analyst's expertise (–)
Plausibility checks	Are there reasonable, quick plausibility checks on the results obtained which are independent of the tool? What ways are there of checking the "correctness" of the results? One example would be checklists	• There are plausibility checks for almost all aspects (+) • There are plausibility checks, e.g. checklists, but they do not necessarily cover all aspects (o) • There exist only limited means supporting plausibility checks (–)
Intellectual rigour	How rigorous is the method? Rigour has two relevant aspects: • Does the method have a rigorous meaning, formal semantics, for the key notions of causal factor and root cause? Are the semantics easy to apply? • Are the results of the method amenable to formal (mathematical) verification? To what extent is an application of the method so amenable?	• Formally defined and can be formally verified (+) • Semi-formal definition (o) • Informal definition (–)
Time sequence	Does the method contain a representation of time sequence of events?	• Yes (+) • Only indirectly (o) • No (–)
Specificity	The extent to which the method limits analysis to necessary causal factors of the focus event rather than exploring a range of general problems with the system that existed at the time of the focus event and may have contributed	• Method only analyses necessary causal factors of the focus event (+) • Method can be used to analyse contributory factors as well as necessary causal factors of the focus event (o) • Method seeks problems in general whether or not they were necessary causal factors of the focus event (–)

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Table A.3 – Attributes of the generic RCA techniques

	Expertise required	Tool support	Scalability	Graphical representation	Reproducibility	Plausibility checks	Intellectual rigour	Time sequence	Specificity
ECF	o	o	o	+	o	o	o	+	+
MES and STEP	–	o	o	+	+	o	o	+	+
The 'Why' Method	+	+	–	o	–	–	–	–	+
CTM	o	o	+	+	o	o	o	–	+
WBA	o	+	o	+	+	+	+	o	+
Fault tree and success tree method	o	o	o	+	o	o	o	–	o
Fishbone or Ishikawa Diagram	+	+	–	o	–	o	–	–	o
SOL	o	–	+	o	+	+	o	+	o
MORT	+	–	–	o	+	o	o	–	–
AcciMaps	o	o	o	+	–	o	–	–	o
Tripod Beta	–	+	o	+	o	o	o	o	o
CAST	+	+	+	o	o	o	o	+	+

NOTE The criteria for each attribute are described in Table A.2.

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Annex B
(informative)

RCA models

B.1 General

This annex describes the most commonly used RCA models which provide different ways of thinking about focus events. The different models are based on certain hypothesis with regard to the focus event, e.g. barrier analysis assumes the focus event has occurred as a result of missing, failed or ineffective barriers. Therefore, the different models tend to lead the investigator to identify different causal factors. Models are used to direct thinking in conjunction with the techniques of Annex C, or simply to identify a set of causal factors.

B.2 Barrier analysis

B.2.1 Overview

Barrier analysis is based on the hypothesis that a focus event occurs as a result of the interaction of a source of harm on a target and that this can be prevented by the use of barriers [3]. An undesirable event occurs when the barriers are missing, failed or ineffective (see Figure B.1).

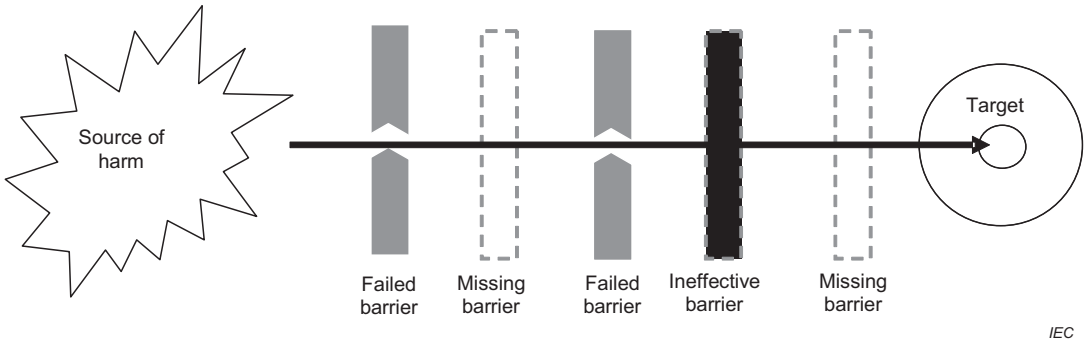

Figure B.1 – Broken, ineffective and missing barriers causing the focus event

Haddon [3] considered focus events where the source of harm is physical energy and barriers relate to how the energy can be modified or prevented from impinging on the target. The model has been extended in various ways [4], for example barriers are often divided into physical barriers and administrative barriers (see Table B.1 for some examples). Barriers may also be considered in terms of prevention, protection and detection (for example in the context where the focus event is a fire, these would be using non-flammable materials, providing fire extinguishers and installing smoke alarms).

The output of the analysis generally includes a barrier analysis worksheet (see Table B.2), which identifies those barriers that either were available but ineffective or were not in place during the occurrence of the focus event.

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Table B.1 – Examples of barriers

Physical or energy barriers	Administrative barriers
Engineered safety features	Plant operating and maintenance procedures
Safety and relief devices	Regulations, policies and practices
Conservative design allowances	Training and education
Redundant equipment	Work protection
Locked doors and valves	Work permits
Ground fault protection devices	Skilled people
Shielding and guards	Methods of communication (3-way communication)
Alarms	Supervisory practices
Automatic fire containment systems	

Table B.2 – Example of the barrier analysis worksheet

Undesired outcome (what happened?) List one at a time, need not be in sequential order	**Source of harm**	**Barrier(s) that should have precluded the undesired event** List all physical and administrative barriers for each undesired outcome	**Barrier failure mechanism (how the barrier failed)**	**Barrier assessment (why the barrier(s) failed)** Identify if the barrier was missing, weak or ineffective; and why
Maintenance worker loosened nuts on flange of the pipe line that was pressurized	Pressurized liquid	Procedure to switch off pump and release pressure before commencing work	Pressure released on wrong system	Unclear labelling

B.2.2 Strengths and limitations

The strengths of barrier analysis are as follows:

- identifies what corrective actions are required to ensure adequate barriers (number and effectiveness) are in place.

The limitations of barrier analysis are as follows:

- may not recognize all failed or missing barriers, or the effect of the rate or frequency with which the barriers are challenged;
- addresses immediate causal factors rather than root causes, i.e. it seeks what barrier failed and how, but does not explore why in any depth.

B.3 Reason's model (Swiss cheese model)

B.3.1 Overview

Reason's model [5] is based on the premise that the basic required elements of any productive system are

- appropriate decisions from plant and corporate management,
- line management activities, operations-maintenance training, etc.,
- reliable and fit for use equipment,
- motivated workforce,

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- integration of human and mechanical elements,
- safeguards against foreseeable risks.

There are inevitably weaknesses in these elements that can be considered to be latent failures. If these come together to form a triggering event, which may be unimportant in other circumstances, this results in failure.

The weaknesses in the elements of the productive system are pictured as holes in slices of Swiss cheese. An event will result when all individual weaknesses align. Reason's model is not strictly a barrier model as the layers are normal operating systems with weaknesses rather than failed barriers or controls.

Human error taxonomies based on Reason's model have been developed for a number of different industries.

B.3.2 Strengths and limitations

The strengths of Reason's model are as follows:

- encourages the analyst to explore causal factors of operator error and hence possible means of reducing it.

The limitations of Reason's model are as follows:

- superficial analysis of technical or environmental causal factors which considers technical aspects only in terms of failed barriers;
- assumes the core problem is operator error (errors at other levels and organizational failures are explored primarily in terms of how they influence operator error);
- does not supply a taxonomy to assist with the identification of motivations and psychological precursors of human error or in identification of latent failures and hence requires expertise in individual and organizational psychology to use properly.

B.4 Systems models

Systems theory [6] was developed in the 1940s and 1950s to handle the increase in complexity of systems after WWII and to consider the social and technical aspects of systems together as a whole.

In system models it is assumed that human interaction with technology in complex social structures is influenced by the organization's goals, policy and culture and by internal and external economic, legal, political and environmental elements. This system is stressed by the fast pace of technological change, by an increasingly aggressive, competitive environment, and by factors such as changing regulatory practices and public pressure. In this context focus events are due to multiple factors and are typically 'waiting for release' and not due to any one act or event.

Failures arise due to the complex interactions between system components that may lead to degradation of system performance. Two or more discrete events within system elements can interact in unexpected ways which designers could not have predicted and operators cannot comprehend or control without exhaustive modelling or test. Factors contributing to the focus event may include effects of decisions which are normal in the circumstances in which they were made, but produce an unwanted outcome.

Methods based on a systems model do not seek a causal chain or look for individual error or technical failures but consider the system as a whole, its interactions and its weaknesses. Individual human or hardware failures may be recognized but the focus is on interactions and systemic issues.

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B.5 Systems theoretic accident model and processes (STAMP)

B.5.1 Overview

STAMP [7] is a causality model based on systems theory [6] that extends the traditional model (chains of directly related failure events) to include both the technical and social contributors to focus events and their relationships. It also captures focus events involving interactions among non-failing system components and processes, indirect and systemic causal mechanisms, complex operator and managerial decision making, advanced technology such as digital systems and software and system design flaws.

STAMP assumes incidents arise from interactions among humans, machines and the environment; it treats systems as dynamic control problems in which the controls aim to manage the interactions among the system components and its environment. The goal of the control is to enforce constraints on the behaviour of the system components, for example, aircraft in an air traffic control system have to always maintain a minimum separation distance. Focus events result from inadequate control or enforcement of constraints on the development, design and operation of the system. In the space shuttle "Challenger" loss, for example, the O-rings did not control propellant gas release through the field joint of the space shuttle. In STAMP, the cause of a focus event is a flawed control structure.

STAMP also incorporates the concept that incidents often arise from a slow migration of the whole system toward a state of high risk [8] so that financial and other pressures that lead to changing behaviour over time can be accounted for in the causal analysis process.

B.5.2 Strengths and limitations

The strengths of STAMP are as follows:

- considers the role of the entire socio-technical system in causation;
- includes indirect and systemic factors in the causal explanation;
- provides a model to explain accidents in very complex systems;
- identifies the causes back to the process with which a system was developed.

The limitations of STAMP are as follows:

- requires focus events to be analysed in a way that is often unfamiliar to engineers, therefore may take more time to learn how to analyse focus events using causal analysis processes based on STAMP.

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Annex C
(informative)

Detailed description of RCA techniques

C.1 General

Annex C describes a range of techniques used during a RCA. The list is not comprehensive but covers examples of the different types of techniques used. Many of these techniques are supported by software tools. Some of the methodologies and software tools have elements that are proprietary, which may impact on the cost of implementing the technique.

Some techniques aim to identify causal factors that can be shown to be necessary if the focus event is to occur. Other methods seek general weaknesses of the system as a whole that probably contributed to the focus event but where the focus event could have occurred in their absence. In some terminologies a “causal factor” cannot be so described unless it is necessary to the focus event. In this annex such causal factors are referred to as “necessary causal factors”. Identified weaknesses that may have played a part in the focus event but may not be necessary to it are referred to as “contributory factors”.

In general, identification of necessary causal factors will be repeatable and based on evidence. There may be a higher level of subjectivity in identifying contributory factors and different analysis techniques with a different focus may identify different factors.

C.2 Events and causal factors (ECF) charting

C.2.1 Overview

The ECF chart [9] records events in chronological order from left to right in rectangles, with events characterized by single subjects and active verbs. Each event is derived strictly from the one before. Conditions necessary for the events are displayed in ovals above and below the sequence of events (conditions are states or circumstances rather than happenings). Events are connected by solid lines and conditions by dashed lines. Events and conditions based on evidence have a solid outline, whereas those that are presumptive have a dashed outline. There may be multiple or branching sequences of events, each with their own conditions.

Figure C.1 illustrates an example of an ECF chart in which a maintenance activity was incorrectly carried out due to the maintainer turning up late, resulting in an emergency landing carried out by an aircraft.

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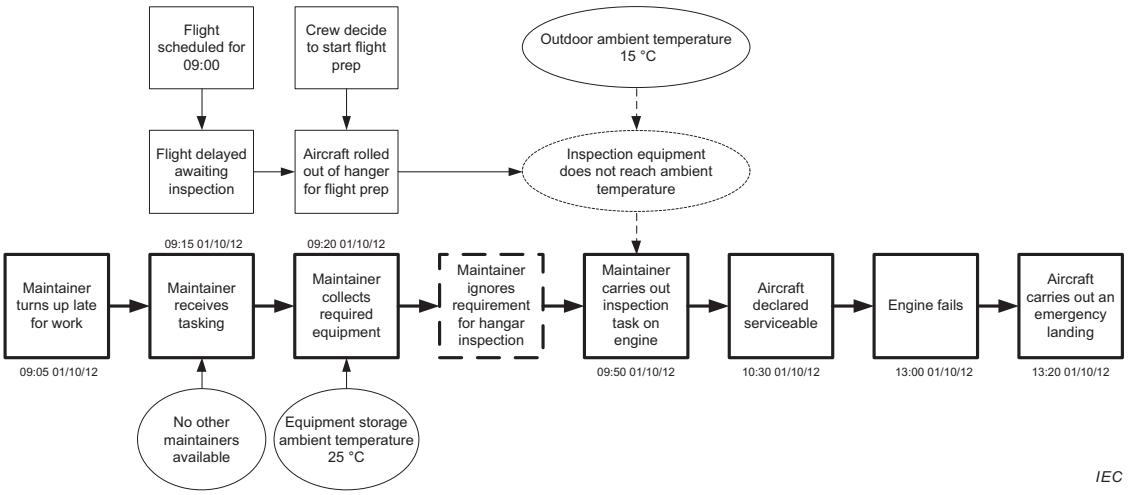

Figure C.1 – Example of an ECF chart

C.2.2 Process

The following describes the process for developing an ECF chart:

a) Identify the focus event and record it in a box on the right hand side.

b) Record the primary chain of events that led to the focus event where each event in the chain is both immediate and necessary to the event on the right hand side. Therefore, the consequence is recorded on the right hand side of each event (causal factor). Also, the consequence of a previous event may be the causal factor of the next event. The events are displayed in rectangles linked by arrows to the right of the focus event.

c) Determine what conditions led to these events. State each of them in an oval above the relevant event.

d) Add any secondary chains of events that may be relevant to the focus event and their conditions.

e) Check the validity of the causal factors by obtaining evidence that determines whether the conditions and events are true.

f) Develop the ECF chart until the event at the start of the sequence is identified and all conditions which can be verified by evidence are added.

In general, the exact chronology of events is not known at the beginning of the investigation but becomes clearer as the investigation proceeds. A method should therefore be used that allows investigators to easily change the sequence of events and conditions as more information is gained.

C.2.3 Strengths and limitations

The strengths of ECF are as follows:

- assists the verification of causal chains and event sequences;
- provides a structure for collecting, organizing and integrating evidence;
- identifies information gaps;
- assists communication by providing an effective visual aid that summarizes key information regarding the focus event and its causes.

The limitations of ECF are as follows:

- identifies some causal factors but may not necessarily determine the root causes;

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- can be overcomplicated for simple problems.

C.3 Multilinear events sequencing (MES) and sequentially timed events plotting (STEP)

C.3.1 Overview

MES [10] and STEP [11] are methods developed to analyse focus events in complex systems, where STEP is a successor to MES.

As with ECF charting, MES/STEP conceives a focus event as arising from an interlinked succession of events with events characterized by a single subject and an active verb. In MES and STEP, the subject is called an actor (which may be a human, a machine or even a property).

Events are represented as event building blocks (BBs), which consist of (partial or full) data records as described in Figure C.2. These are arranged during the analysis in a time-actor matrix where the vertical axis of the matrix represents the different actors, and the horizontal axis represents time.

The time-actor matrix also contains:

- conditions necessary for enabling an event along with precursor events;
- annotations for further tasks in an investigation, such as a note indicating a deficit of information, or an incomplete explanation of an event.

An example showing part of the representation of a tank maintenance event is given in Figure C.3.

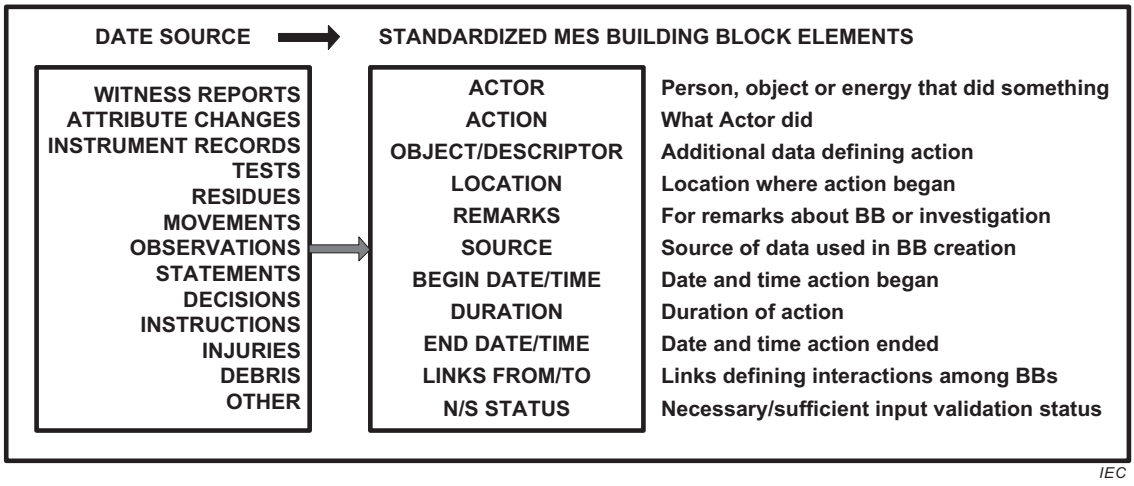

Figure C.2 – Data in an event building block

C.3.2 Process

MES/STEP has the following steps:

a) Gather information for the initial series of building blocks, and identify and track missing information.

b) Arrange the initial building blocks in an initial time-actor matrix.

c) Identify and generate hypotheses to "fill" the gaps with events (in the form of further building blocks).

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d) Terminate the process when an analyst considers that sufficient information is available in the time-actor matrix.

C.3.3 Strengths and limitations

MES/STEP has the same strengths and limitations as ECF. Data formatting is relatively more elaborate, and there are explicit mechanisms for determining and tracking missing data and attempts to determine those data. Some such “bookkeeping” mechanisms are necessary for managing complex investigations with multiple investigators. The time-actor matrix also has explicit notation for recording the state of an on-going inquiry along with data-acquisition and explanatory tasks yet to be performed. This means that a comprehensible visual representation of the state of an investigation is available at all points in an investigation.

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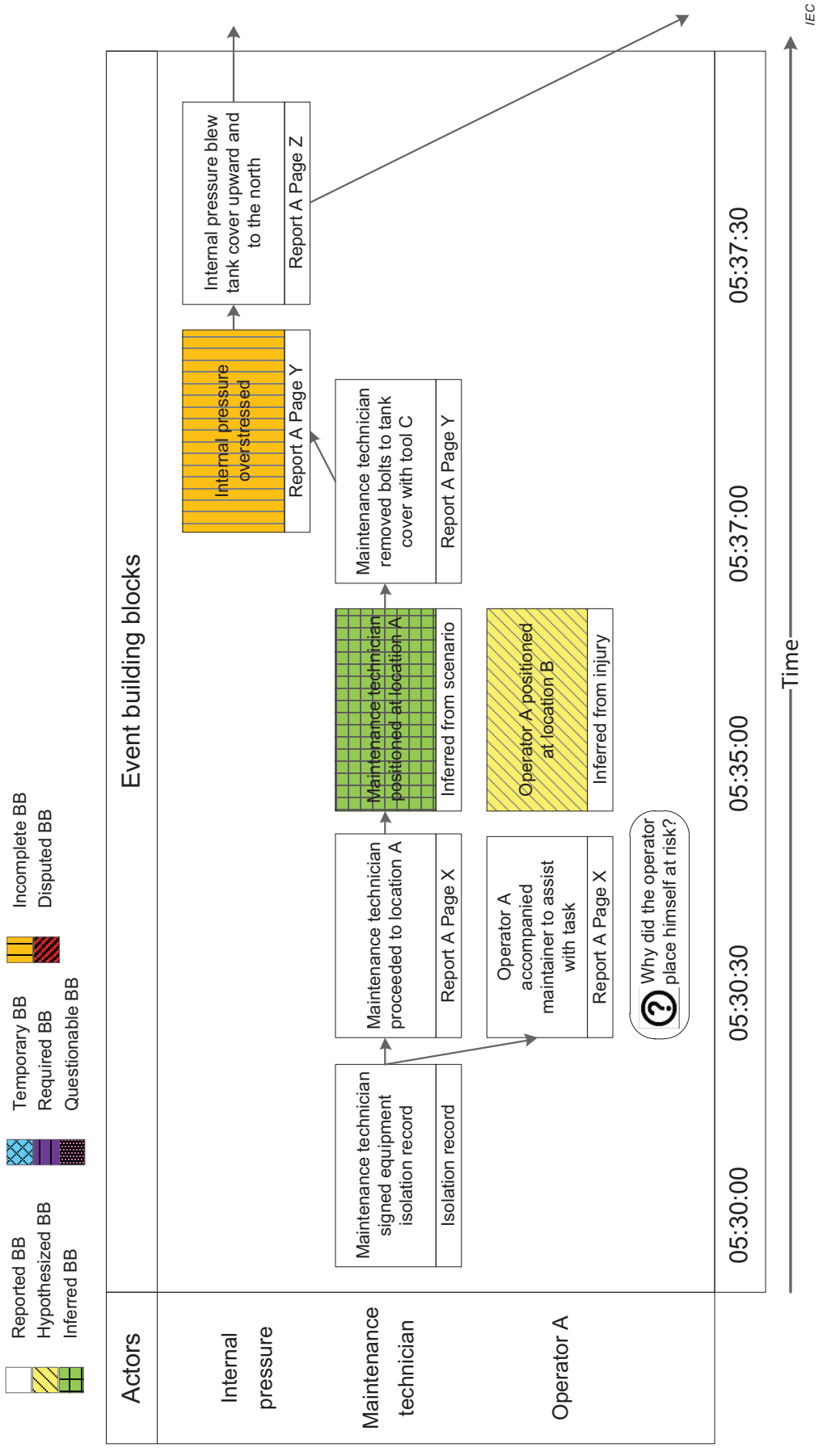

Figure C.3 – Example of a time-actor matrix

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C.4 The 'why' method

C.4.1 Overview

The 'why' method uses a straightforward questioning process to arrive at the root causes.

Questioning starts with a statement of the situation and asks why it occurred. The answer to this question is turned into a second why question and the answer to this into a third question. Questioning ceases when the stopping rule is reached. Generally this requires approximately 5 levels of questions hence the method is sometimes known as the 5 whys.

Where a why question provides several causal factors, each is explored and the method produces a why tree.

The why method is used alone for simple situations but is also inherent in more complex tree methods such as the causes tree method (CTM) (see Clause C.5). It can be useful for eliciting information from witnesses on how and why an event occurred because the simple question 'why' does not make assumptions about cause or lead the witness.

Figure C.4 illustrates an example of a compressor that has experienced an unscheduled shutdown. In the example the fourth why suggested a number of potential causal factors for lack of lubrication and evidence was sought to define which in fact occurred. Although a human error was involved in that a person did not follow specified start up procedures, the recommendation is to improve the design so the compressor and pump motors are linked. Further analysis of why the error occurred, in this case, is not useful.

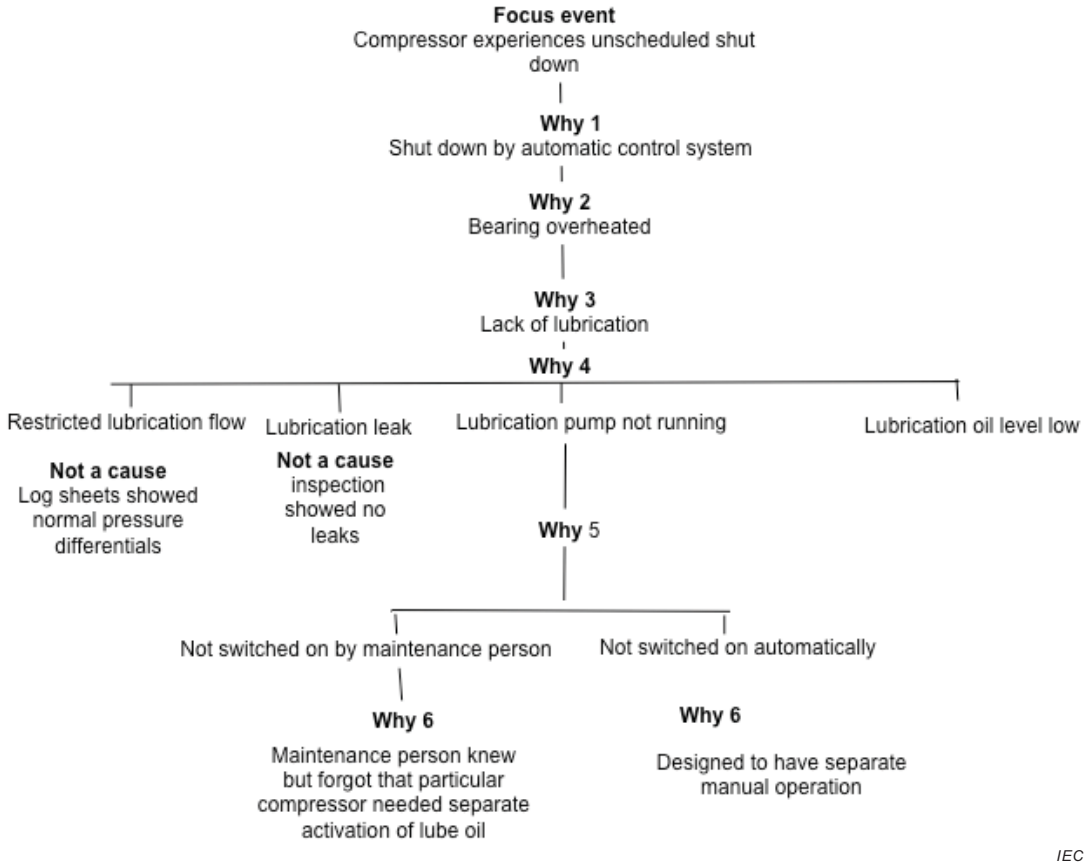

Figure C.4 – Example of a why tree

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C.4.2 Process

The ‘why’ method has the following steps:

- Identify and record the focus event as the start of a 'why' diagram.
- Ask why the focus event occurred, seeking only the immediate causal factors.
- Ask “why” successively with respect to the previous answer. In each case the answer to the question "why" should be an immediate causal factor of the previous answer.

The question ‘why’ is asked as many times as is needed to lead to a root cause, which is normally five questions but this is only a guideline. Each time the question is asked, there may be multiple answers and some analysis will be needed to eliminate those possible answers that are not applicable. It may be more effective to ask ‘why did the process fail?’ instead of just asking ‘why’?

It can be useful to consider a set of categories of cause such as from the Ishakawa method and to involve a team of people. This will help ensure that all relevant areas are considered by the investigators.

C.4.3 Strengths and limitations

The strengths of the ‘why’ method are as follows:

- simple to apply by those involved in the problem;
- easy to understand by others;
- quick process to achieve results for simple problems;
- does not require extensive knowledge from the person asking the questions;
- does not require a lot of training from the person asking the questions.

The limitations of the ‘why’ method are as follows:

- only suitable for simple situations;
- heavily dependent on the knowledge and expertise of the people answering the questions, with expertise in both technical failure modes and human error often required to reach the root causes;
- root causes are likely to be missed if outside the knowledge base of those involved;
- possible uncertainty about when the appropriate root causes have been identified;
- can be developed to the level where reasons for people’s actions are being considered, where evidence is often not available and results are therefore not always repeatable.

C.5 Causes tree method (CTM)

C.5.1 Overview

CTM [12] is a systematic technique for analysing and graphically depicting the events and conditions that contributed to a focus event.

The method examines all the system components associated with the focus event. The investigation starts by establishing the tangible facts, taking care, in this phase, not to interpret them or to express an opinion about them.

CTM is similar to the why method in concept but builds a more complex tree and explicitly considers technical, organizational, human and environmental causal factors. Each antecedent (identified causal factor) is tested to check it is an immediate and necessary causal factor of the previous one, whereas the why method is less rigorous. Therefore, CTM is suitable for more complex situations.

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CTM is also similar to a fault tree but, whereas a fault tree is used prior to an event to explore all possible causal factors and strict logic relationship(s) between faults are specified, the cause tree includes only those causal factors which apply to a specific event that has already occurred and does not develop the logical relationships in detail.

A cause tree may be used to explore successes as well as failures.

The cause tree forms a network of the causes which have directly or indirectly caused the focus event, using the three logical relations shown in Figure C.5.

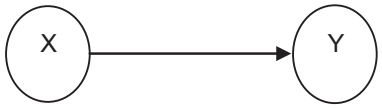
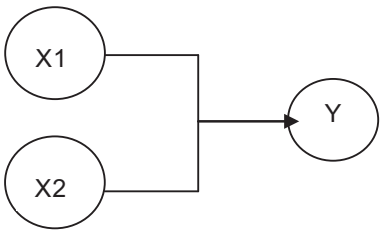
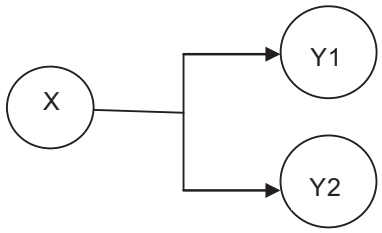
Sequence: A cause (Y) has a single direct origin (X). i.e. (X) was necessary and sufficient for (Y) to occur	
Conjunction: A cause (Y) has several direct origins (X1) and (X2). That means, each of the direct origins (X1) and (X2) was necessary for (Y) to occur	
Disjunction or separation: Two or more causes (Y1;Y2, …) have a single and identical direct origin (X). That means (X) was necessary for (Y1) and (Y2) to be produced.	

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Figure C.5 – Symbols and links used in CTM

Figure C.6 shows an example tree, in which Mr L (the victim) and Mr A are working nights, as an exception, to store a surplus of stock. In accordance with the handbook, Mr L and Mr A were required to load the crusher with "flour" which is then bagged and stored. Normally this activity is under the responsibility of a head of team whose presence had not been considered essential by the management for this night. Of his own initiative to save time, Mr L took a forklift truck (the ignition key had remained on the dashboard as usual) to store the bags. At the end of the task, Mr L set about returning the forklift truck. Mr L carried out a sharp bend in reverse, forks raised, and while seeking to avoid a hole on the ground the forklift tipped over, crushing Mr L between the ground and the right safety upright of the truck.

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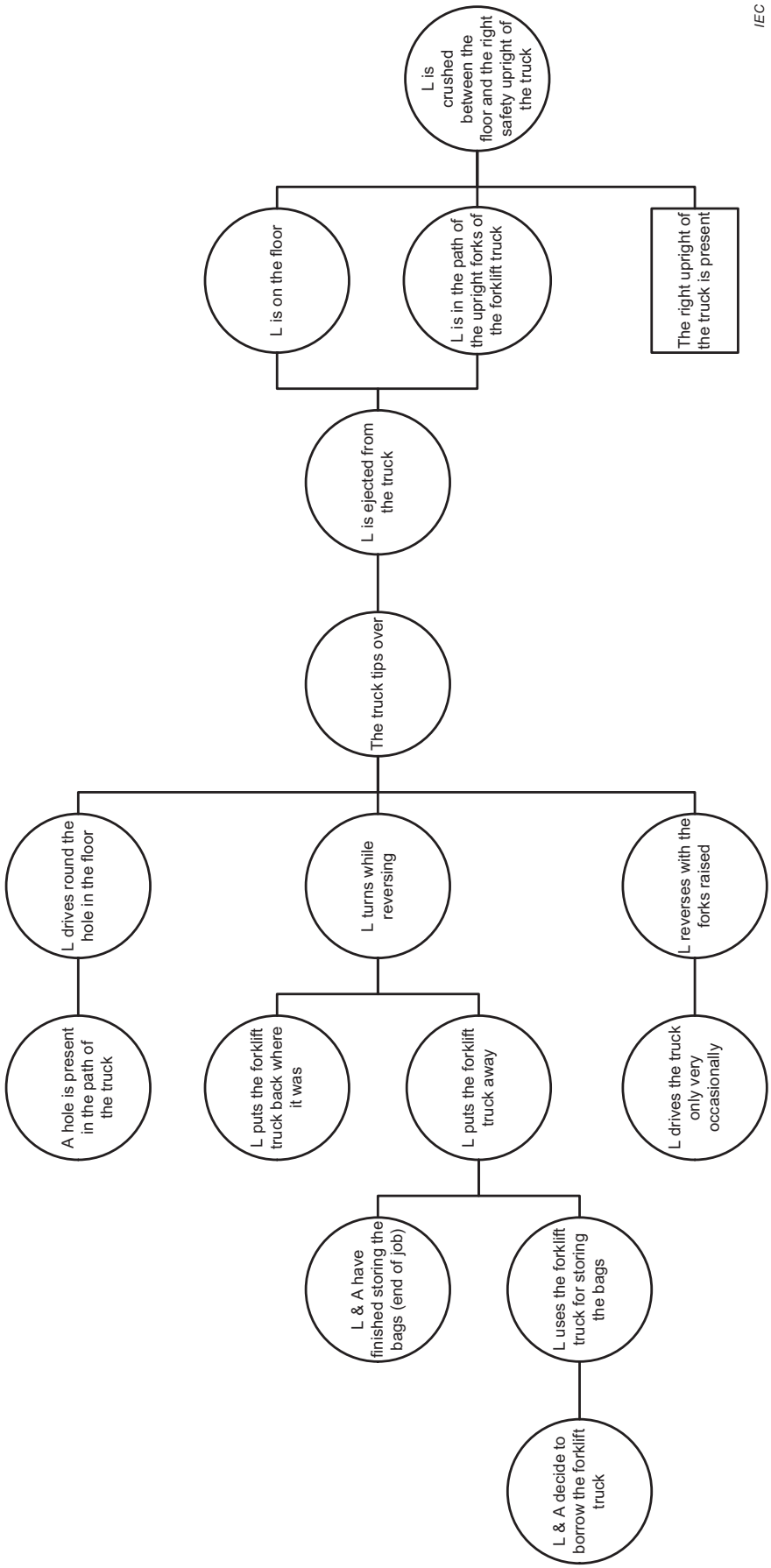

Figure C.6 – Example of a cause tree

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C.5.2 Process

CTM has the following steps:

a) Identify the focus event to be analysed and record it as the starting point for the tree.

b) Collect and record all relevant data including people, their activities and actions, materials and equipment and factors relating to the physical and psychosocial environment.

c) Make a list of the causal factors to the focus event. These should be supported by evidence and be expressed as precisely as possible. Subjective opinions and judgements are not included. Causal factors include those which are unusual or change the normal course of events and those which are normal but played an active part in the occurrence of the event.

d) Work backwards towards the root causes by asking the following questions systematically for each antecedent that has been gathered:

   1) what antecedent X has directly caused the antecedent Y?;

   2) was X in itself necessary to give rise to Y?;

   3) If not, what are the other antecedents (X1, X2...) that were equally necessary in order to give rise directly to Y?

e) Display these immediate necessary causal factors in a box linked by an arrow to the focus event. The tree may be drawn horizontally or vertically but is normally drawn horizontally starting from the right, so that left to right corresponds to the chronology of events.

f) Continue asking the same questions with respect to each necessary causal factor found until the team agrees that there is no value in continuing further.

g) Check the validity of the tree by obtaining further evidence that determines whether it is true.

C.5.3 Strengths and limitations

The strengths of CTM are as follows:

- provides a method for structuring investigation of complex events;
- facilitates easy to read format;
- can be used to encourage group participation;
- identifies areas for collecting data as the investigation proceeds;
- can be used to analyse success or failure events;
- can be used for technical and non-technical events.

The limitations of CTM are as follows:

- many human and organizational factors may contribute to the occurrence of the focus event and it is often difficult to establish which in a particular instance were the necessary causal factors;
- there is no guidance on how to seek causal factors; therefore, expertise in human error and organizational systems is needed when the tree involves human and organizational failures, where evidence is often difficult to obtain;
- it is difficult to apply when an event occurs as a result in a change of quality in several areas, where no single causal factor is a necessary causal factor.

C.6 Why-because analysis (WBA)

C.6.1 Overview

WBA [13] is a causal-analytical technique for establishing which of a given collection of events and situations are necessary causal factors. Given two events or situations, A and B

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say, a condition called the counterfactual test (CT) is used to establish whether A is a necessary causal factor of B. Suppose two events or situations A and B have been observed. The CT asks whether, had A not occurred, B would also not have occurred. (Since A did occur, a supposition that A had not occurred is contrary to fact, hence the word "counterfactual".) In asking this question, all other conditions are assumed to have remained the same. If the answer is yes: B would not have occurred then A is a necessary causal factor of B. If the answer is no: B could have happened anyway even if A had not happened (the CT fails) then A is not a necessary causal factor of B.

The network of causal factors is displayed as a Why-because graph (WBG), a collection of "nodes", boxes, diamonds and other shapes, containing a brief description of the fact, joined by "edges", or arrows, where the node at the tail of an arrow is a necessary causal factor of the node at its head, as determined by the CT.

A WBA is acyclic (contains no loops), so is usually drawn with arrows pointing in the generally upwards direction, as shown in Figure C.7, or horizontally with arrows pointing generally left-to-right, or right-to-left.

In order to determine whether sufficient causal factors are present in the collection of events and situations presented, the causal completeness test (CCT) is used. The CCT is applied to a given event or situation and its collection of necessary causal factors as determined by the CT. If the CCT is not passed, then the collection of events and situations has to be extended by further factors until it is passed. Suppose A_1, A_2,...,A_n have been determined to be necessary causal factors of B by the CT. Then the CCT is deemed to be passed if, had B not occurred, one of A_1, A_2,...,A_n would not have occurred either (formally, NOT-B is a necessary causal factor of NOT(A_1 AND A_2 AND...AND A_n) as determined by the CT).

When a WBG has been constructed and the CCT is passed for all the events and situations therein, then the WBG is complete and is deemed to represent a sufficient causal explanation of the focus event.

Figure C.7 illustrates an example of a WBG for a commercial-aviation runway-overrun accident.

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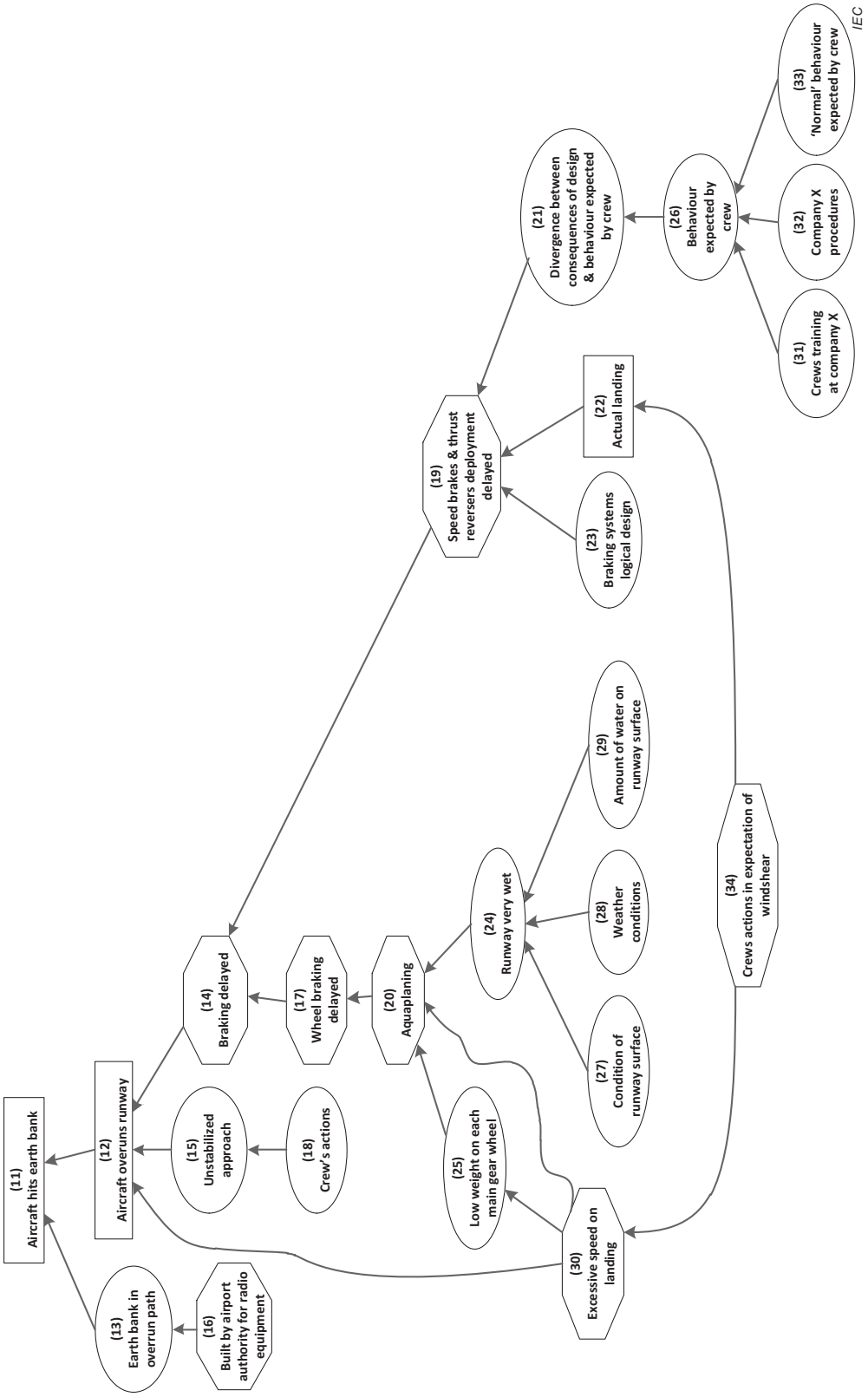

Figure C.7 – Example of a WBG

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C.6.2 Process

WBA has the following steps:

a) Determine a collection of facts deemed to be relevant, under guidance of a stopping rule. This gives an initial collection C of facts, divided into events, states and situations.

b) Select the focus event (called in WBA the accident event).

c) Determine intuitively the immediate necessary causal factors of the focus event from amongst the collection C; check using the CT. Display the results visually as a partial WBG.

d) Determine intuitively the necessary causal factors of those immediate factors; check using the CT. Extend the WBG with these factors.

e) Proceed to fill out the analysis (to extend the WBG) by testing each fact in C against the factors already in the WBG.

f) Apply the CCT to determine whether the WBG is complete, or whether factors are missing from the collection C.

g) Extend C if necessary; incorporate the new facts into the WBG using the CT. If insufficient information is available, assumptions may be included, providing they are clearly labelled as such.

h) Finish when the CCT shows sufficient causal factors for each fact, in conformity with the stopping rule. If insufficient facts are available, assumptions have to be included in order to allow the CCT to succeed, but clearly labelled as such.

C.6.3 Strengths and limitations

The strengths of WBA are as follows:

- may be performed with a minimum of training (with the use of suitable tools that provide help on extracting facts from narrative descriptions, an inexperienced analyst can typically perform a first pass WBA inside two hours);
- the analysis results are easily understandable by third parties;
- the conceptual background required to perform a WBA is limited (an analyst must be able to apply the CT, and then the CCT);
- any network of causally-related phenomena may be analysed with a WBA;
- the reasoning behind a WBA may be formally checked using a formal logic;
- can be used together with other methods, e.g. those providing more structure to the collection of facts.

The limitations of WBA are as follows:

- the method provides no guidance on the collection of facts to which the tests are applied e.g. there is no structuring of facts into categories such as technical, procedural, human-factors, organizational and legal;
- because facts are not structured, WBA provides limited guidance on corrective action in the case where recurrence needs to be prevented.

C.7 Fault tree and success tree method

C.7.1 Overview

A fault tree [14] displays the immediate necessary causal factors of a focus event, their causal predecessors and the logic relationships between them. Fault tree analysis (FTA) [15] is normally used as a priori method of identifying and analysing potential failure modes, particularly of equipment. The fault tree diagram can be used in RCA by building a tree following the same logic but including in the tree only those events which actually occurred.

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OR gates may be used during the analysis to describe alternative causal factors that need to be evaluated, but when all facts are clearly established only AND gates should remain, unless the purpose of the investigation is to prevent other related events. Therefore, as the investigation proceeds, potential causal factors that do not fit the evidence are gradually ruled out and removed from the tree. By closing out each branch of the tree, the causal factors of the focus event become apparent.

Strictly a fault tree represents binary events where a statement is true or false, e.g. a component failed or not. In RCA, the fault tree structure is often applied to a tree of causal factors where the logic rules are not strictly obeyed and changes in quality are included as well as binary events.

A similar logic can be applied where the focus event is a success. In this case the tree is referred to as a success tree.

Figure C.8 shows an example of a fault tree.

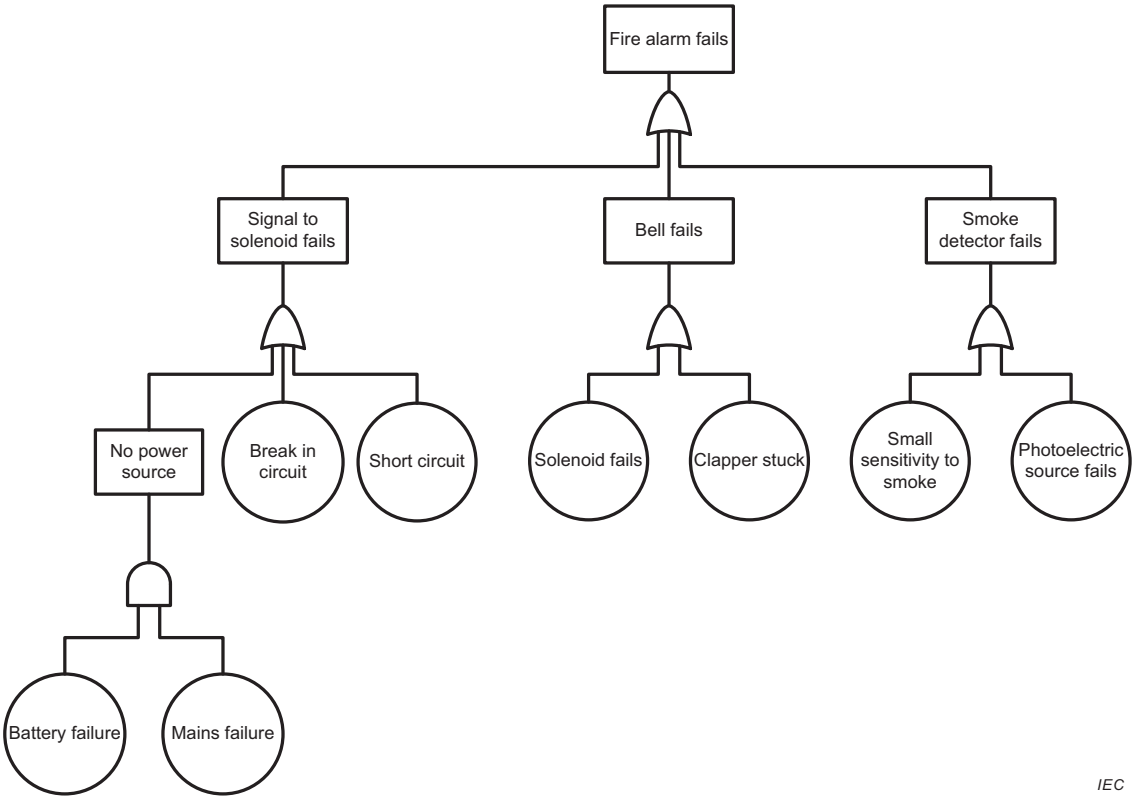

Figure C.8 – Example of a fault tree during the analysis

C.7.2 Process

The process for developing a fault/success tree is as follows:

a) Define the focus event to be analysed and record it as the starting point for the tree.

b) Establish the immediate necessary causal factors of the focus event and display them in a box linked by an arrow to the focus event. The tree may be drawn horizontally or vertically. These are the first level causal factors of the focus event.

c) Establish the logic relationships between the immediate causal factors using AND and OR Gates. The events at inputs of an AND gate have to be both necessary and sufficient to

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cause the event above. OR gates may be used during the analysis to describe potential causal factors that require investigation.

d) Examine each causal factor to decide whether it is a root cause or the result of underlying causal factors.

e) Validate potential causal factors and update the tree accordingly.

f) Continue down the tree until the stopping rule is reached.

When the tree is developed, the possibility of causal factors relating to people, equipment and the environment is considered for each causal factor at each level. These should not be separated out at the top of the tree.

C.7.3 Strengths and limitations

The strengths of the fault/success tree method are as follows:

- provides a method for dividing up the analysis for large complex focus events;
- supported by many commercial software packages which assist in the development of the fault tree structure;
- encourages group participation;
- uses an orderly, easy-to-read format;
- identifies areas for collecting data.

The limitations of the fault/success tree method are as following:

- requires an experienced practitioner;
- has no underlying model of causation and provides no guidance on how to seek causal factors;
- does not easily represent situations where an event occurs as a result of a general changing of quality that affects for example adherence to procedures or tolerances of physical components.

C.8 Fishbone or Ishikawa diagram

C.8.1 Overview

The Fishbone or Ishikawa diagram [16] is a technique that helps identify, analyse and present the possible causes of a focus event. It may be used to structure a brainstorming session and to suggest ideas where further evidence may be sought. The technique was invented by Kaoru Ishikawa and graphically illustrates the relationship between an event and all the factors that influence it. This technique is also referred to as a "fishbone diagram" because of its appearance.

Figure C.9 shows an example of a Fishbone or Ishikawa diagram.

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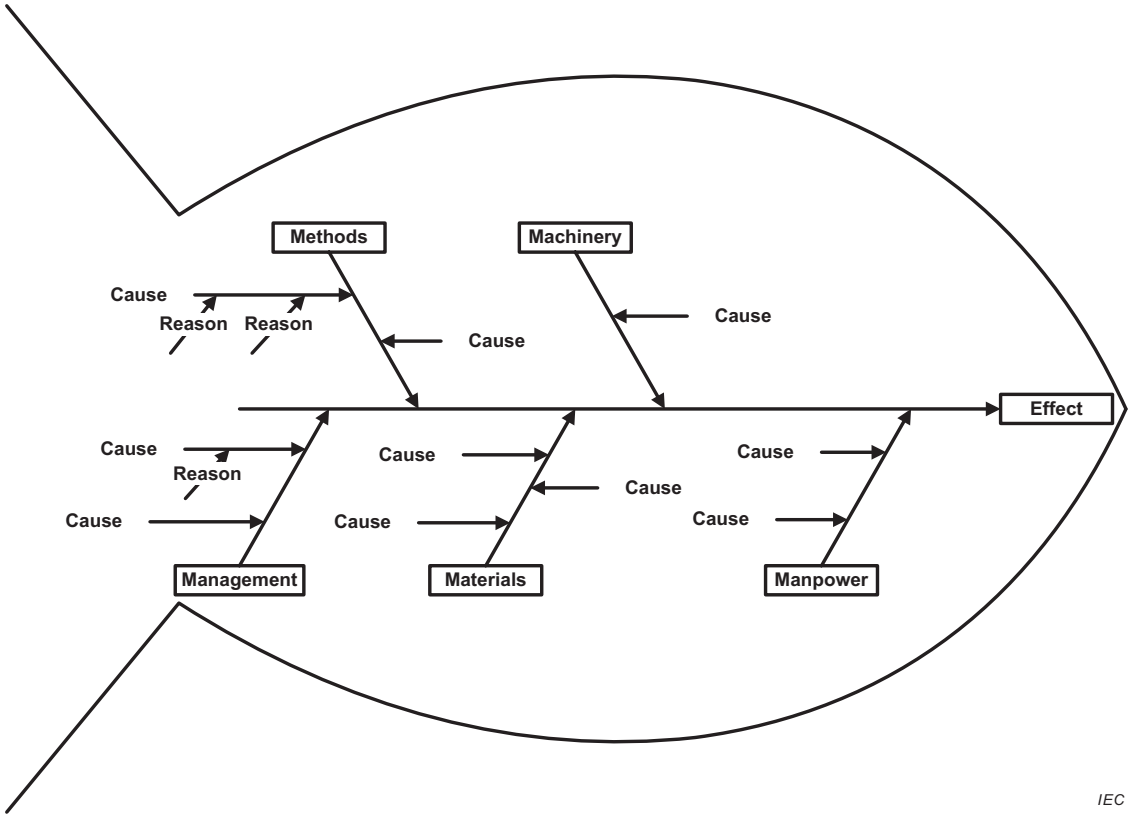

Figure C.9 – Example of a Fishbone diagram

C.8.2 Process

The process for developing a Fishbone or Ishikawa diagram is as follows:

a) Identify the focus event and record it on the right hand side and draw a line horizontally from it. This forms the head and spine of a fish.

b) Establish the main categories of causes to be considered and draw lines off the spine to represent each category. Categories commonly used include:

   1) 5Ms: methods, machinery, management, materials, manpower;

   2) 4Ps: place, procedures, people, policies;

   3) 4Ss: surroundings, suppliers, systems, skills.

c) For each category identify the possible causal factors of the focus event. These are presented as smaller lines coming off the 'bones' of the fish. Increasingly more detailed levels of causal factors can be shown as sub-branches coming off each cause line. It may be necessary to break the diagram into smaller diagrams if one branch has too many sub-branches.

d) Analyse the diagram: The diagram now shows all the possible causal factors of the focus event. The final step is to investigate the most likely causal factors which tests whether the analysis is correct. Analysis includes:

   1) reviewing the “balance” of the diagram, checking for comparable levels of detail to identify the need for further identification of causal factors;

   2) identifying causal factors that appear repeatedly as these may represent root causes;

   3) assessing what can be measured in each cause in order to quantify the effects of any changes made;

   4) highlighting the causal factors whose action can be taken.

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C.8.3 Strengths and limitations

The strengths of the Fishbone or Ishikawa diagram are as follows:

- encourages group participation to identify people's perceptions of causal factors;
- seeks causal factors under a set of categories, so will identify a range of causal factors relating to human and organizational factors as well as hardware and procedural factors;
- uses an orderly, easy-to-read format;
- indicates possible causal factors of variation;
- can be used for simple investigations or as part of a more complex investigation.

The limitations of the Fishbone or Ishikawa diagram are as follows:

- there is no underlying model or theory of causation, so the causal factors identified are based on the team's perceptions.

C.9 Safety through organizational learning (SOL)

C.9.1 Overview

SOL [17] is an event analysis technique, which seeks weaknesses in the complex socio-technical system in which the event occurred. The purpose of SOL is to provide a model of the system and identify its weaknesses so it can be improved and recurrence of the focus event prevented. The emphasis is on organizational learning.

C.9.2 Process

SOL has the following steps:

1) Describe the situation using a time-actor matrix produced by MES/STEP (see Clause C.3).
2) Identify causal factors (which may be direct or indirect see Table C.1) for each event in the time-actor matrix, guided by checklists of questions derived from the experience and research of SOL authors. Direct causal factors are those that immediately resulted in the focus event, indirect causal factors appear further down the causal chain but may involve the same issues.
3) Classify causal factors into technology, individuals, working group, organization, and organizational environment.

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Table C.1 – Direct and indirect causal factors

Direct causal factors	Indirect causal factors
Information	Information
Communication	Communication
Working conditions	Working conditions
Personal performance	Personal performance
Violations	Violations
Technical components	Scheduling
	Responsibility
	Control and supervision
	Group influence
	Rules, procedures and documents
	Qualifications
	Training
	Organization and management
	Safety principles
	Quality management
	Maintenance
	Regulatory and consulting bodies
	Environmental influences

C.9.3 Strengths and limitations

The strengths of SOL are as follows:

- the check list format allows users who are not specialists in organizational systems or organizational psychology to produce useful analyses;
- the emphasis on causal factors rather than necessary causal factors allows more factors to be brought into consideration than a narrowly causal analysis might do, and thereby offers more chance of identifying possible improvements;
- the format of the event building blocks gives less scope to the judgement of individual analysts and helps to give uniformity to SOL analyses;
- the stopping rule is implicitly defined by the checklist questions: when these have been answered, the information is deemed to be adequate.

The limitations of SOL are as follows:

- there is no specific notion of what is a causal factor other than what is implicit in the checklist questions;
- the level of detail is driven by the predetermined checklist of questions rather than the perceived need;
- the check list of questions was derived from research in the nuclear power industry and may be less suitable for other industries.

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C.10 Management oversight and risk tree (MORT)

C.10.1 Overview

MORT [18] was first developed for analysing the root causes and causal factors for incidents in the nuclear power and aviation industries in the USA, but now has been applied in many industries.

MORT is a pre-populated tree based on a model of an organization's management system, which effectively provides a detailed check list for reviewing which parts of management and control systems were less than adequate when the focus event occurred. The basic structure of the tree is shown in Figure C.10.

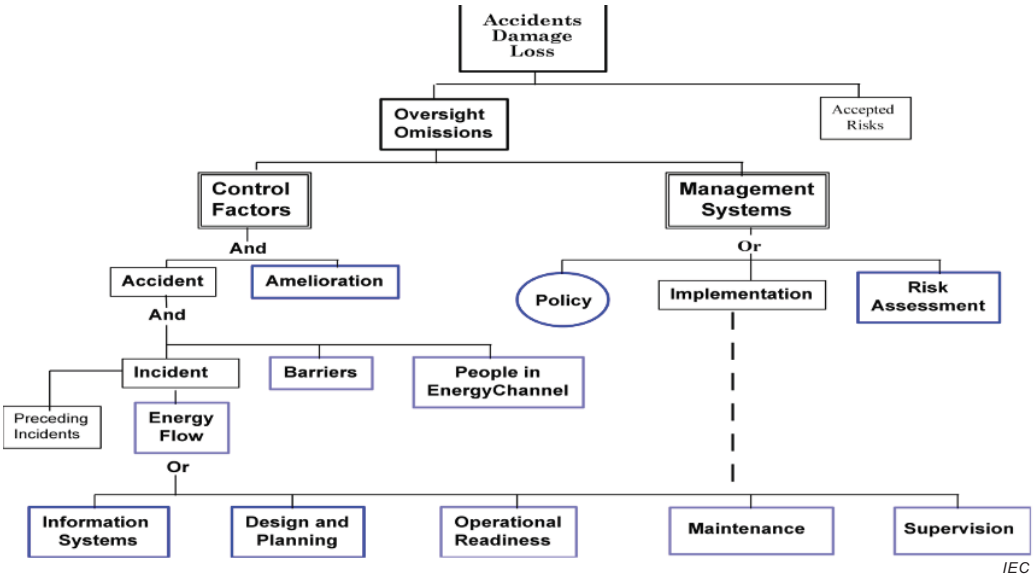

Figure C.10 – Example of a MORT diagram

MORT assumes that a failure occurs as a result of oversights or omissions in either management systems or the specific control factors which should have prevented the focus event from occurring.

Ultimately, failures in either branch in the tree occur because something within the general management systems (information systems, design and planning, operational readiness, maintenance or supervision) was less than adequate. Each box in Figure C.10 is developed into a detailed tree structure showing factors that might have been less than adequate.

C.10.2 Process

Start with the focus event and then work down the MORT tree in a logical manner asking and responding to pre-questions in the MORT manual. Symbols on the MORT chart are colour coded to indicate:

- there is no problem with an element (adequate);
- the element is giving rise to a problem (less than adequate);
- there is need for further enquiries.

C.10.3 Strengths and limitations

The strengths of MORT are as follows:

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- provides comprehensive guidance for seeking all possible aspects of the system that were not adequate at the time of the focus event;
- less specialist expertise is needed than in some techniques because detailed guidance is provided on possible causal factors;
- identifies weaknesses in the system which might apply across a wide range of failure scenarios.

The limitations of MORT are as follows:

- explores weaknesses in the system in general that might have played a role in the focus event rather than seeking immediate or necessary causal factors;
- a very large number of questions (around 1 500) are asked, so the method is time consuming and hence most appropriate for serious events;
- unless the organization to which it is applied is a high reliability organization a very large number of weaknesses are found which make it difficult to implement changes;
- tedious when first learning or applying the method.

C.11 AcciMaps

C.11.1 Overview

AcciMaps [19] is based on concepts of causation published by Rasmussen and Svedung [20] and the organizational systems model (see Clause B.4).

AcciMaps is a graphical representation used to structure the analysis of a focus event and to identify the interactions in the socio-technical system in which the focus event occurred. It is a method designed to reveal the system wide failures, decisions and actions involved in a focus event. These are arranged in layers representing the different levels in a socio-technical system from government down to the equipment and surroundings involved. It also looks at the individual actors at each level and their decision-making routines and competence.

An example AcciMap for a gas explosion, showing typical system levels, is given in Figure C.11. The bottom level represents the physical arrangement of the scene of the focus event (buildings, equipment, surroundings, etc.). The next level up is the sequence of events leading to the focus event, including the failures, actions and decisions (including normal actions and decisions) that played a part. The higher levels show decisions and actions at each level that influenced, or could have influenced, the sequence of events at the lower levels.

C.11.2 Process

An AcciMaps is developed as follows:

a) Define a model of the system with different organizational levels.
b) Populate the levels (using boxes (nodes)) with the decisions and actions relevant to the focus event, the conditions that lead to them and their consequences.
c) Draw arrows that show all linkages and influences.
d) A process such as WBA may be added to ascertain which of the identified issues were necessary causal factors of the focus event.

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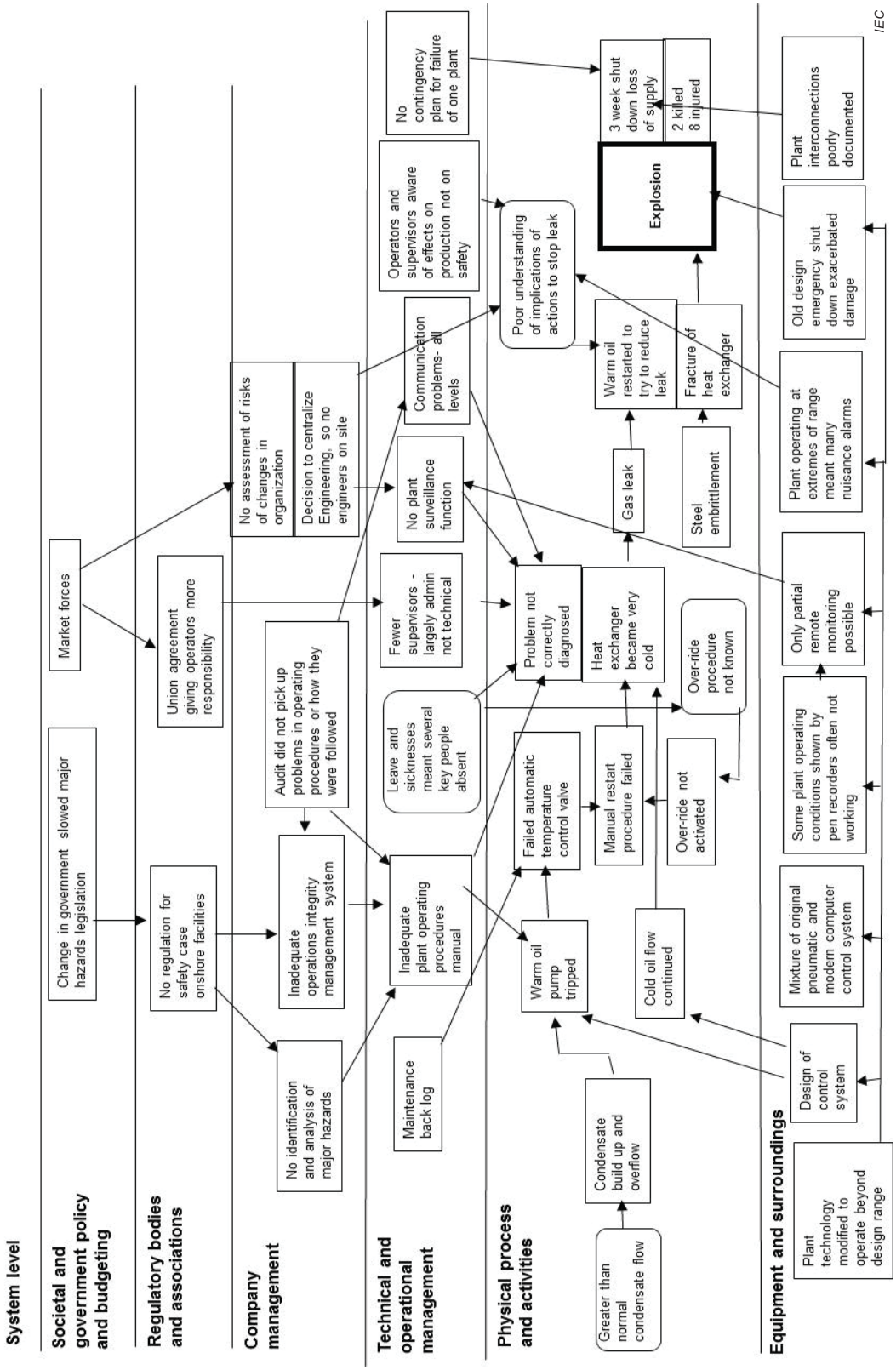

Figure C.11 – Example of an AcciMap

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C.11.3 Strengths and limitations

The strengths of AcciMaps are as follows:

- as there is no taxonomy or guidance, AcciMaps has the potential to be highly comprehensive in identifying causal factors across all levels of the system;
- the linkages within and between levels helps ensure that failures are considered in the context of the things that influenced them;
- human error has equal focus with equipment and higher level organizational factors;
- personal factors which influence decisions, particularly at the lower levels, are not included.

The limitations of AcciMaps are as follows:

- the lack of a taxonomy means that the factors identified are based on the team's perception;
- the organizational model comes from outside the analysis and there is no criterion to ensure it is adequate;
- the result of the AcciMaps analysis is lightly constrained, therefore it is possible to derive different AcciMaps for the same focus event;
- with no specific taxonomy it is difficult to aggregate multiple analyses to find common factors;
- the generality of factors in the nodes is often high and can be very abstract. This makes it difficult to derive precise actions;
- it has a weak analytical approach to physical and equipment failures;
- it does not represent the results of a causal analysis by itself.

C.12 Tripod Beta

C.12.1 Overview

Tripod Beta [21] is an incident investigation and analysis methodology which combines the ideas from Reason's model (see Clause B.3) and Barrier Analysis (see Clause B.2), along with Rasmussen's generic error modelling system (GEMS) and Wagenaar's Tripod causation path. It describes incidents in terms of 'objects', e.g. people, equipment, etc. being changed by 'agents of change', e.g. anything with the potential to change an object. It also models 'barriers', showing them, for example, as effective, failed or inadequate.

Tripod Beta provides a format and rules for modelling the events (focus event and the events leading up to, and after, the focus event) and linking each element together, working back ultimately to the underlying causes. A number of software packages have been developed based on these rules, but it can be used with or without software. The software–based techniques contain checklists derived from the models and from analysis of past events mostly in the off shore oil industry.

The core of a Tripod analysis is a 'tree' diagram representation of the causal network (see Figure C.12) which describes the focus event as a network of events and their relationships.

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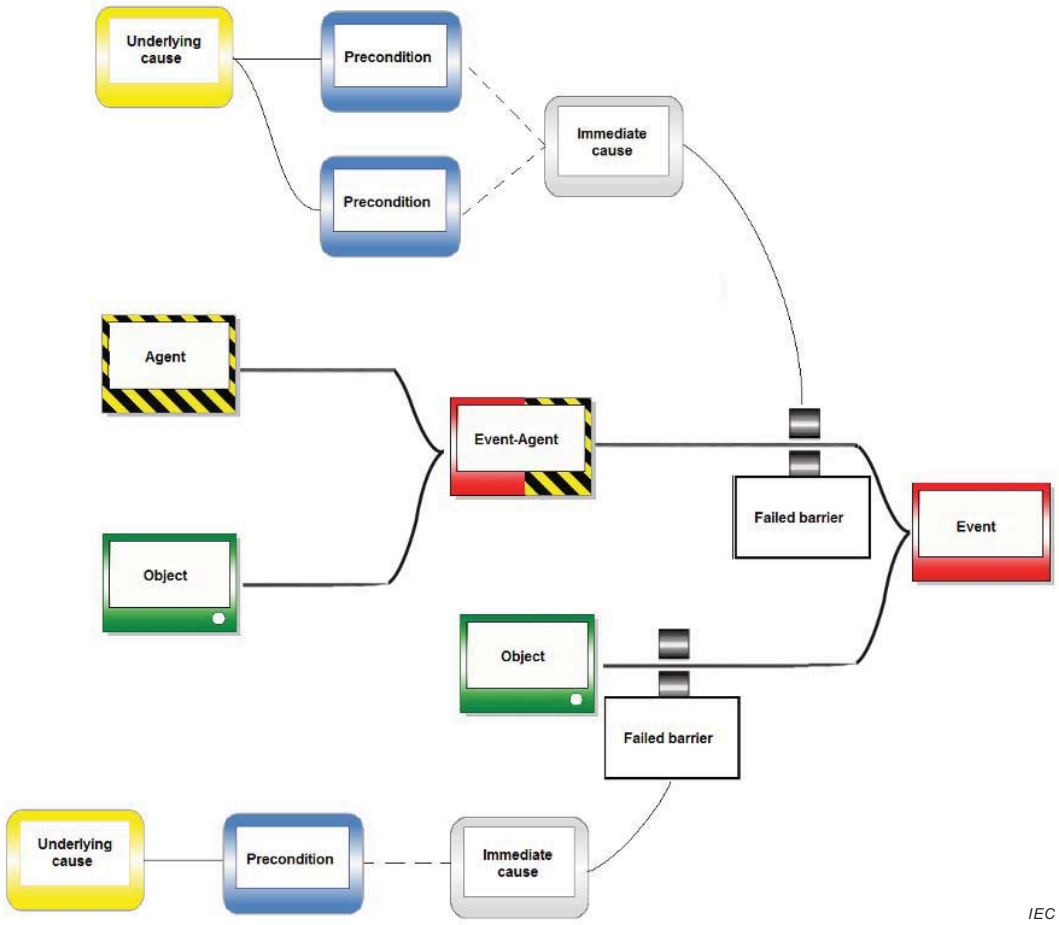

Figure C.12 – Example of a Tripod Beta tree diagram

C.12.2 Process

The process for developing the Tripod Beta tree diagram is to identify the following:

a) The agent (hazard or hazards) that lead to the focus event and the target that was harmed.

b) Controls or barriers, that were missing or failed, that could have prevented the event or protected the target.

c) Immediate causes – the human act, which resulted in the failed barrier. These are failures or errors that have immediate effect and occur at the point of contact between a human and a system (e.g. pushing an incorrect button, ignoring a warning light).

d) Preconditions – psychological and situational precursors e.g. the type of human failure (slip, lapse, violation, etc.).

e) Underlying causes (latent failures) in the organization, i.e. inadequacies in the management system, culture, etc. These can be categorized into pre-defined 'basic risk factors', derived from brainstorming and research into results of audits and accident investigations in the off shore oil industry.

C.12.3 Strengths and limitations

The strengths of the Tripod methodology are as follows:

- provides a map of the focus event and its causal factors;
- can help direct the investigation and define its scope;

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- defines the barriers in the system;
- based on scientific research including a model of human behaviour to uncover what is behind the observed behaviour;
- leads the investigator to consider the reasons behind the immediate causes and human error;
- menu driven software is available.

The limitations of the Tripod methodology are as follows:

- can be resource intensive;
- leads to system level underlying causes which an organization might not be able to accept;
- use of the basic risk factors to categorize underlying causes can be too generic and simplistic;
- conclusions do not lead to simple remedial actions;
- extensive training is generally required.

C.13 Causal analysis using STAMP (CAST)

C.13.1 Overview

CAST [7] is a technique that examines the entire socio-technical process involved in a focus event. CAST is based on STAMP (see Clause B.5), which is used to guide the causal analysis. CAST documents the dynamic process leading to the focus event, including the socio-technical control structure as well as the constraints that were violated at each level of the control structure and why. The analysis results in multiple views of the focus event, depending on the perspective and level from which the focus event is being viewed.

To illustrate CAST, consider a focus event involving the contamination of a public water supply with E. coli in a small town in Canada. Figure C.13 shows the safety control structure for the water supply of the town. There are three physical systems being controlled: the well system, the water supply and public health. Each component in the structure controlling these processes has specific safety-related responsibilities. For example, the Ministry of the Environment provides oversight and control of the local water systems. Each component of the control structure gets feedback about the state of the process it is controlling. One common cause is that the controller gets incorrect feedback and thinks the state of the controlled process is different than it is. For example, budgets were cut and the Ministry of the Interior reduced the number of inspections and inspectors.

Figure C.14 shows the analysis of the role of the local health department in the focus event, including the roles and responsibilities, the unsafe control actions, the context in which the unsafe control actions were provided, and the flaws in the process (mental) model that contributed to the behaviour. Figure C.15 shows the same thing for another component of the control structure, the water system operations management.

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In a full analysis, each component of the control structure would be considered with respect to their contribution to the focus event. In most focus events, contributions can be found from every component of the control structure.

Other features of the analysis (not shown) include examining the dynamic changes over time in the system that contributed to the focus event and the role of flawed communication and coordination.

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System hazard: Public is exposed to E. coli or other health-related contaminants through drinking water.
System safety constraints: The safety control structure must prevent exposure of the public to contaminated water.
1) Water quality must not be compromised.
2) Public health measures must reduce risk of exposure if water quality is compromised (e.g. notification and procedures to follow)

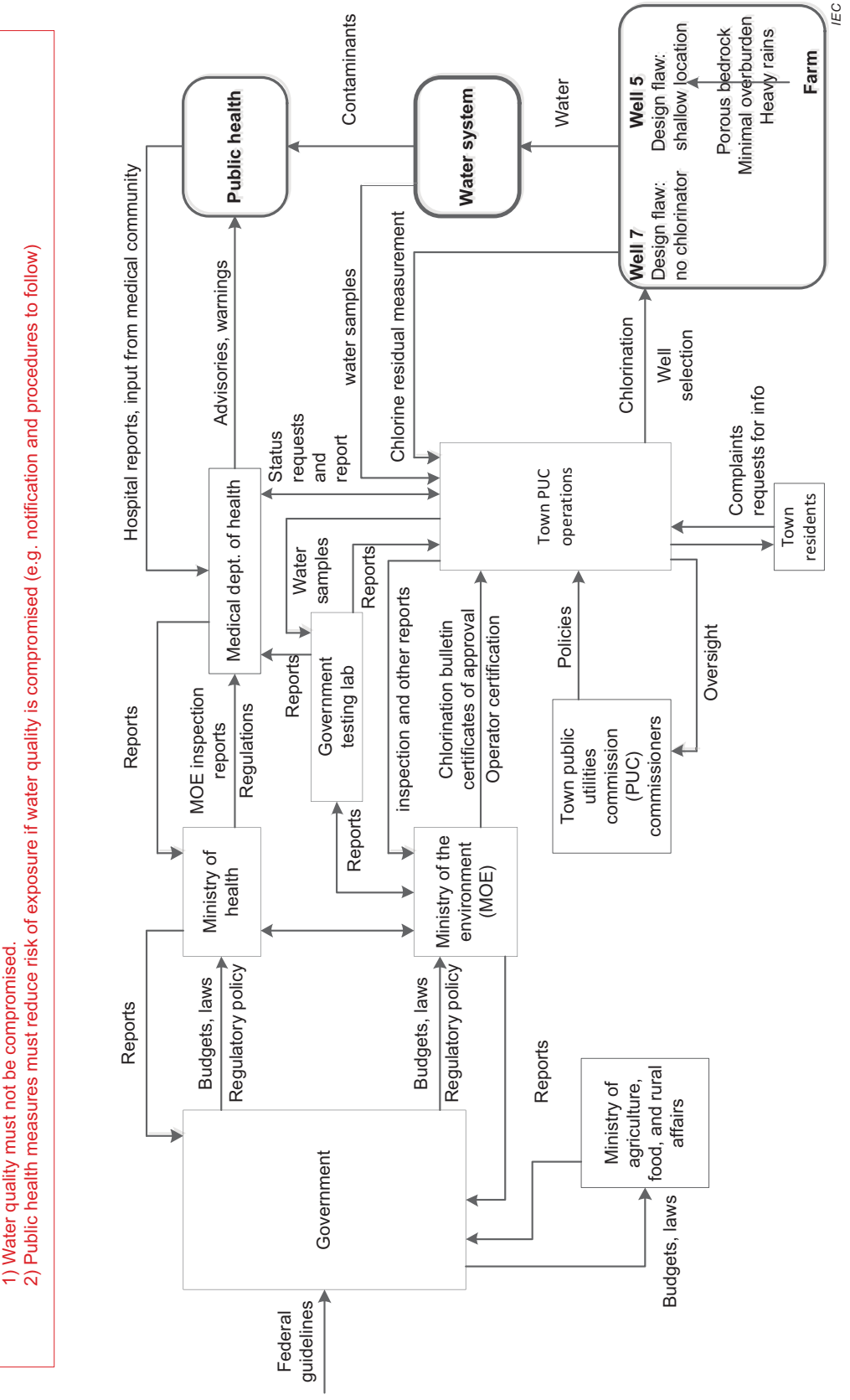

Figure C.13 – Control structure for the water supply in a small town in Canada

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Medical department of health

Safety requirements and constraints:

- Provide oversight of drinking water quality
- Follow up on adverse drinking water quality reports
- Issue boil water and other advisories if public health at risk

Context in which decision made:

- Most recent water quality reports over 2 years old
- Illness surfacing in communities outside the town
- E. coli most commonly spread through meat

Inadequate control actions:

- Advisory delayed
- Advisory should have been more widely disseminated
- Public health inspector did not follow up on 1998 inspection report

Mental model flaws:

- Thought adverse water quality reports were being received
- Unaware of reports of E. coli linked to treated water
- Thought Mr K was relaying the truth
- Unaware of poor state of local water operations

Coordination

- Assumed the ministry of environment was ensuring inspection report problems were resolved

Figure C.14 – Example CAST causal analysis for the local Department of health

Town PUC operations management

Safety requirements and constraints:

- Monitor operations to ensure that sample taking and reporting is carried out
- Keep accurate records
- Update knowledge as required

Context in which decision made:

- Complaints by citizens about chlorine taste in drinking water
- Improper activities were an established practice for 20 years
- Lacked adequate training and expertise

Inadequate control actions:

- Inadequate monitoring and supervision of operations
- Adverse test results not reported when asked
- Problems discovered during inspections not rectified
- Inadequate response after first symptoms in community
- Did not maintain proper training or operations records

Mental model flaws:

- Believed sources for water system were generally safe
- Thought untreated water was safe to drink
- Did not understand health risks posed by under chlorinated water
- Did not understand risks of bacterial contaminants like E. coli
- Did not believe guidelines were a high priority

Figure C.15 – Example CAST causal analysis for the local public utility operations management

C.13.2 Process

CAST has the following steps:

a) Identify the system(s) involved in the focus event.

b) Identify the system constraints associated with the focus event.

c) Document the control structure in place. This structure includes the roles and responsibilities of each component in the structure as well as the controls provided or created to execute their responsibilities and the relevant feedback (if any) provided to help them do this.

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d) Determine the proximate events leading to the focus event.

e) Analyse the focus event at the physical system level. Identify the contribution of each of the following to the events: physical and operational controls, physical failures, dysfunctional interactions, communication and coordination flaws, and unhandled disturbances. Determine why the physical controls in place were ineffective.

f) Moving up the levels of the control structure, determine, as follows, how and why each successive higher level allowed or contributed to the inadequate control at the current level.

   1) For each system constraint, either the responsibility for enforcing it was never assigned to a component in the control structure or a component(s) did not exercise adequate control to ensure their assigned responsibilities were enforced in the components below them.

   2) Identify unsafe decisions or control actions, including actions provided by software, operators, managers, regulators, etc.

   3) Any human decisions or flawed control actions need to be understood in terms of the information available to the decision maker as well as any information that was not available, the behaviour shaping mechanisms (the context and influences on the decision making process), the value structures underlying the decision, and any flaws in the process models (mental models) of those making the decisions and why those flaws existed.

g) Examine the overall coordination and communication (including missing feedback) that contributed to the focus event.

Although the process is described in terms of steps, the process need not be linear nor does one step need to be completed before the next one is started.

C.13.3 Strengths and limitations

The strengths of CAST are as follows:

- looks back through time to determine how the system evolved to a state of high risk;
- identifies the social and managerial factors and not just the human operations or technical system failures;
- does not impose any particular social theory on the analysis, any model of social behaviour could be used to generate the analysis results.

The limitations of CAST are as follows:

- it is not possible to graphically present the analysis, as the inclusion of indirect relationships between causal factors means that circles and arrows (which depict direct relationships) are not adequate to describe all the causal factors;
- may require more resources and time to fully understand the focus event than other methods with a more limited focus.

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Annex D
(informative)

Useful tools to assist root cause analysis (RCA)

D.1 General

Annex D describes tools and techniques that can support the conduct of RCA.

D.2 Data mining and clustering techniques

D.2.1 Overview

Modern data mining techniques enable a search for specific properties and conditions. Clustering analysis selects data that are closely related, and thereby identify deviating data (outliers). Modern cluster analysis can detect data that are closely related in one, two or more dimensions and thereby analyse products or processes that are closely related and identify deviating data points (outliers).

In RCA, data mining and clustering analysis can give valuable clues and help to confirm or reject potential root causes. In some cases, e.g. aerospace and medical equipment, it is required to store batch numbers for the finished products and the associated component batch numbers and raw material batch numbers. This information can provide a useful structure for identifying correlations which hint at possible causal relations.

D.2.2 Example 1

A company observes 12 % failures of stocked items. Analysis shows that a plastic part is broken. The start of the 12 % failure pattern is identified as a batch number and a manufacturing date. This date is correlated with delivered batches of the plastic parts. There is no correlation. There is no correlation either with the batches of plastic raw materials. However, there is a correlation with the batches of a spring that load the plastic part. The problem started 3 days after a new batch of springs was received. The changes that were made between the two batches of springs is investigated. The difference is a new surface treatment against corrosion. This surface treatment process is investigated and contains a note that this treatment may interfere with certain plastic materials. Further analysis shows that the corrosion protection accelerates crack propagation in this plastic. Analysis of the data sheet for the plastic material shows a warning against local overload that may cause cracks. The conclusion therefore is that a causal hypothesis can be formulated: that a plastic part is continuously overloaded and undergoes fracture through local overload, and the fractures propagate in a manner accelerated by the new anti-corrosion treatment of the springs. These cracks then propagate in an accelerated manner due to the new anti-corrosion treatment of the springs. A failure analysis has previously shown a pattern on the fracture surface consisting of crack propagation lines originating in the points of contact with the spring and a brittle surface from the final fracture. The causal-explanatory hypothesis may be confirmed at a given level of confidence by experiment: setting up a number of plastic parts with and without the new treatment. If it is observed that plastic parts with the new treatment predominantly fail, one may conclude that the causal hypothesis is confirmed to the appropriate degree of confidence using standard methods of statistical inference.

D.2.3 Example 2

A number of soldering failures is observed in the field. The manufacturing weeks for the failed products are plotted in calendar time. It is observed that the manufacturing dates of the products with soldering failures are clustering in certain weeks. A causal hypothesis may be formulated on the basis of the initial observation, which is then confirmed to a given degree of confidence using standard statistical inference on the process-control data from

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manufacturing, which indicate that the soldering process in these weeks was likely not performed under appropriate control. The conclusion is, to a high level of confidence, that a root cause of the soldering failures is insufficient process control of the solder process.

D.2.4 Example 3

A component is tested on a test board by twisting the board. The number of twists to failure is plotted on a Weibull plot (see IEC 61649 [22]). The analysis identifies a ”weak” and a ”strong” population (see IEC 61163-1 [23]). One component from the weak and one component from the strong population is analysed by cross-sectioning of the micro ball grid array (BGA) solder balls. It is noted that the component from the weak population has a large number of large voids in the solder balls, while the solder balls from the strong population have no or few small voids. It is concluded that a root-causal hypothesis is formulated, that voids in the solder balls of the micro BGA are a root cause of the incident events. The root-causal hypothesis is confirmed by collecting data on operational use and observing through analysis of the data that the reduction in voids correlates with successful use of the component.

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Annex E
(informative)

Analysis of human performance

E.1 General

People at any level in an organization make decisions or perform or omit actions which may play a part in the events leading to a focus event. Human performance may be above or below expectation and the impact may be positive or negative. Decisions can be correct in the circumstances in which they were made but turn out to have unintended results.

People may make errors, be misguided or misinformed, be inappropriately motivated, may be trying to perform correctly or may knowingly violate rules. Analysis of human aspects of causation is complex and generally requires specialist expertise if it is required to go beyond identifying what occurred to seeking why and hence making recommendations.

E.2 Analysis of human failure

Analysis of human failures starts by identifying the error mode. This is the external manifestation of the error, i.e. what is observed to have been done (or not done). Examples of error modes are as follows:

- omitted;
- too early;
- too late;
- too much;
- too little;
- wrong direction;
- wrong object;
- wrong action;
- wrong sequence.

There are then a number of different taxonomies for categorizing and analysing causes of these errors. They differ in the number and types of classifications they consider and in the models of human behaviour on which the taxonomies are based and on where the most emphasis is placed. The following are generally considered:

a) The internal error mode and error mechanism. This is the reason behind the error in psychological meaningful terms e.g. for an error mode of “took a wrong turn in car”, the internal error mode and mechanism might be incorrect decision due to habit intrusion.

b) Inherent problems of the task, e.g. conflicting goals, planning problems, constraints, cognitive demands etc.

c) Performance shaping factors (PSF). These are the conditions of the technical or organizational environment or internal to a person which affect how well a task will be performed (see IEC 62508 [24]).

Some models also include an analysis of the flow of information and feedback without which correct judgements are unlikely to be made. The importance of these methods is that they first identify the psychological error mechanism before identifying why the error was made. For example if the error mechanism is not due to a lack of knowledge or skill, then further training is unlikely to be useful. If a decision is made to violate a procedure, then the reasons why this occurred should be investigated rather than assuming increased supervision is the solution.

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Two examples of methods which can be used to analyse the causes of human failure which illustrate these principles are:

- Technique for retrospective and predictive analysis of cognitive errors (TRACEr);
- Human factors analysis and classification scheme (HFACS).

E.3 Technique for retrospective and predictive analysis of cognitive errors (TRACEr)

E.3.1 Overview

TRACEr [25] was developed for use in air traffic control. TRACEr, has eight modules as shown in Figure E.1, which can be divided into the following three categories:

- the context in which the error occurred, i.e. the nature of the task, the environment and the PSFs;
- the production of the error, i.e. the external error modes (EEM), internal error modes (IEM), the psychological error mechanisms (PEM) and the information on which the individuals based their actions;
- the detection and correction of the error.

The error production modules are based on the cognitive processes involved when a person perceives something needs to be done and takes action, e.g. perception, memory, decision-making and action (see Figure E.2).

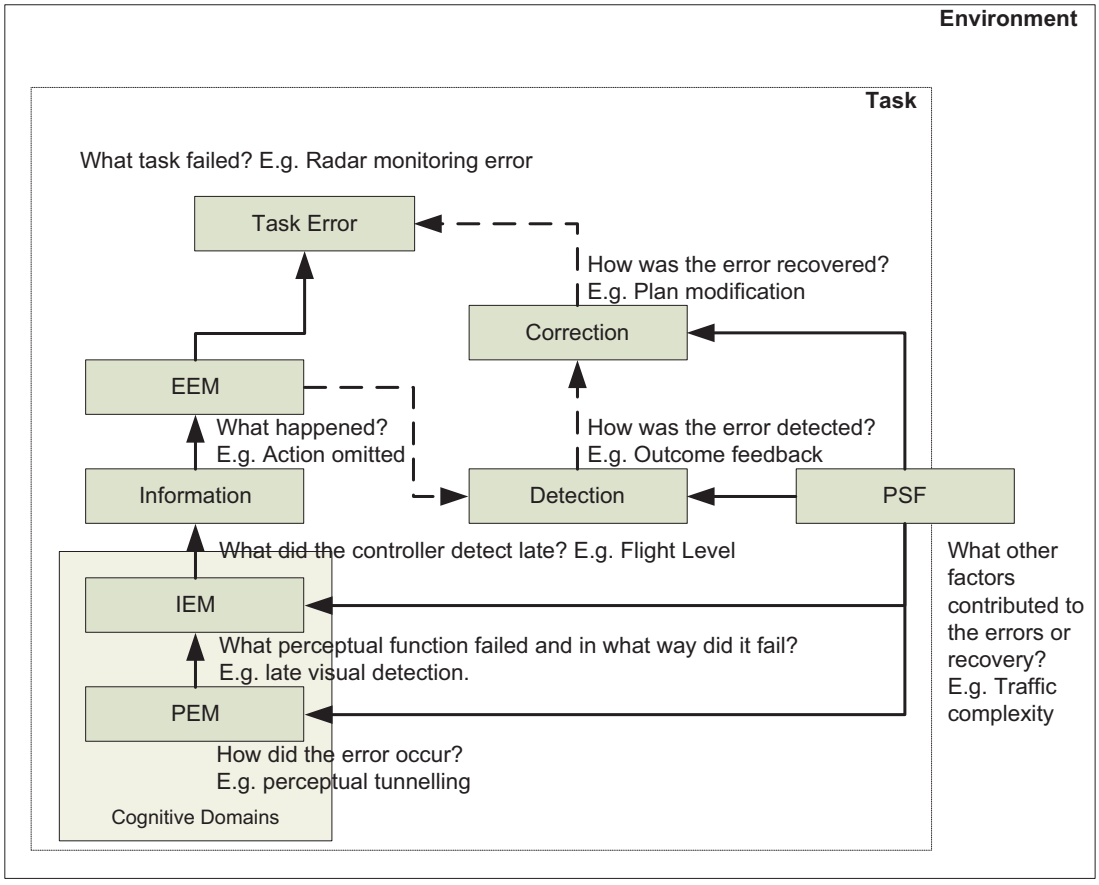

Figure E.1 – Example of an TRACEr model [25]

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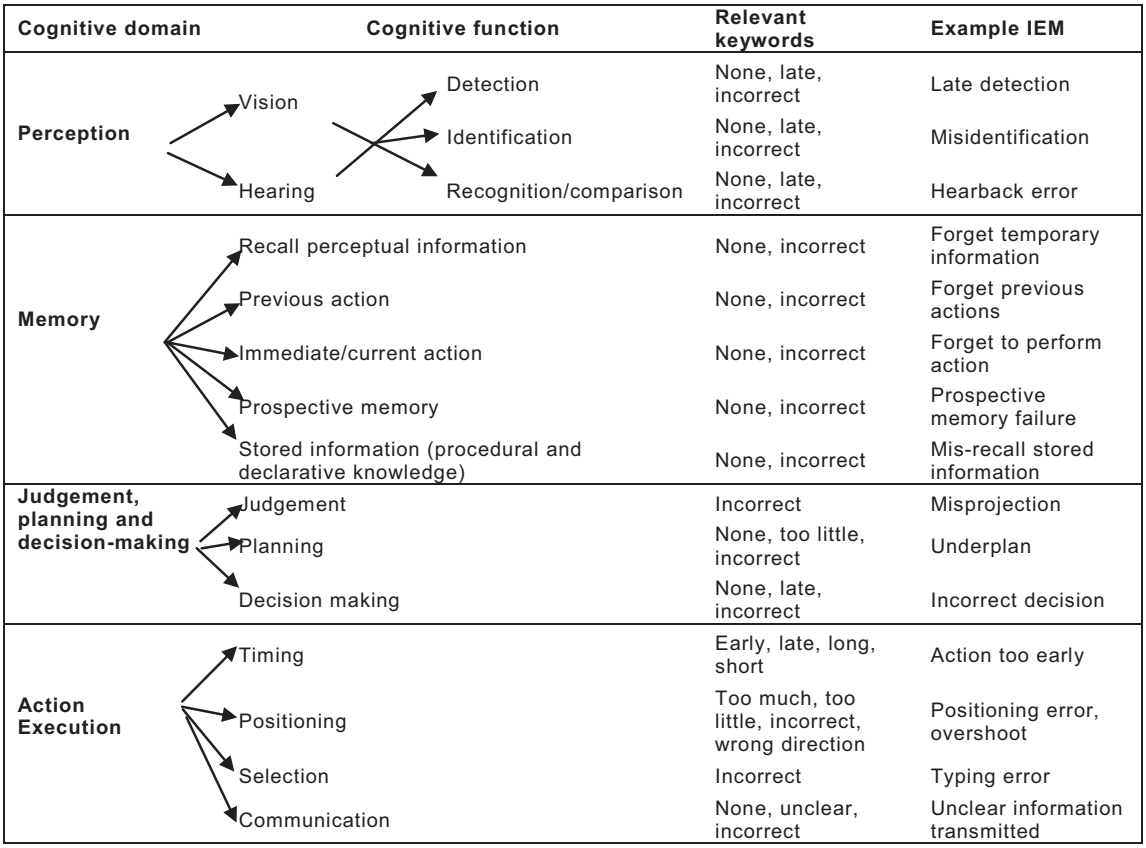

Figure E.2 – Generation of internal error modes

E.3.2 Process

A TRACEr model is created using the following steps:

a) Analyse the task being carried out and identify any environmental or situational factors that might affect human performance (PSF), which includes task complexity, knowledge and experience of the person, the ambient environment, etc.

b) Identify EEMs, which are classified in terms of selection and quality, timing and sequence, and communication (see Table E.1).

c) Identify the IEMs, which describe what cognitive function failed and in what way, the taxonomy for which is shown in Figure E.2.

d) Identify the information issues associated with the IEM, i.e. what information was misperceived, forgotten, misjudged or mis-communicated.

e) Identify the PEMs, which are the cognitive biases known to affect performance within each cognitive domain (see Table E.2).

f) Review the error detection process, which is how the person became aware of the error, what medium informed them of the error and what external factors improved or degraded detection.

g) Consider correction, i.e. what was done to correct the error, did other factors internal or external improve or degrade the error correction.

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Table E.1 – External error modes

Selection and quality	Timing and sequence	Communication
Omission	Action too long	Unclear information transmitted
Action too little	Action too short	Unclear information received
Action too much	Action too early	Information not sought/obtained
Action in wrong direction	Action too late	Information not transmitted
Right action on wrong object	Action repeated	Information not recorded
Wrong action on right object	Mis-ordering	Incomplete information transmitted
Wrong action on wrong object		Incomplete information received
Extraneous act		Incomplete information recorded
		Incorrect information recorded

Table E.2 – Psychological error mechanisms

Perception	Memory	Decision making	Action
Expectation bias	Similarity interference	Incorrect knowledge	Manual variability
Spatial confusion	Memory capacity overload	Lack of knowledge	Spatial confusion
Perceptual confusion	Negative transfer	Failure to consider side effects	Habit intrusion
Perceptual discrimination failure	Mis-learning	Integration failure	Perceptual confusion
Perceptual tunnelling	Insufficient learning	Misunderstanding	Mis-articulation
Stimulus overload	Infrequency bias (memory failure due to knowledge not being used sufficiently frequently)	Cognitive fixation	Environmental intrusion
Vigilance failure	Memory block	False assumption	Other slip
Distraction	Distraction/ preoccupation	Prioritization failure	Distraction preoccupation
		Risk negation or tolerance	
		Risk recognition failure	
		Decision freeze	

E.4 Human factors analysis and classification scheme (HFACS)

E.4.1 Overview

HFACS [26] was developed by behavioural scientists in the Unites States Navy and analyses the causes of human error based on Reason's model (see Clause B.3). There are four levels of consideration based on Reason's model of slices of Swiss cheese:

- organizational influences;
- supervision;
- preconditions for unsafe acts;
- unsafe acts.

Some applications add a fifth level above organizational influences relating to legislation and government.

E.4.2 Process

Each level is subdivided into categories; examples are given of possible causal factors within the category. Different applications use the same categories (shown in the boxes below) but

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may have different examples depending on the industry, and may provide a few examples or a more detailed check list. Examples of the four levels are shown in Figure E.3 to E.6.

Consideration of cause starts with Level 1 so that precursors for the act in question take account of the type of error involved then continues up through the levels seeking weaknesses that contributed to the focus event.

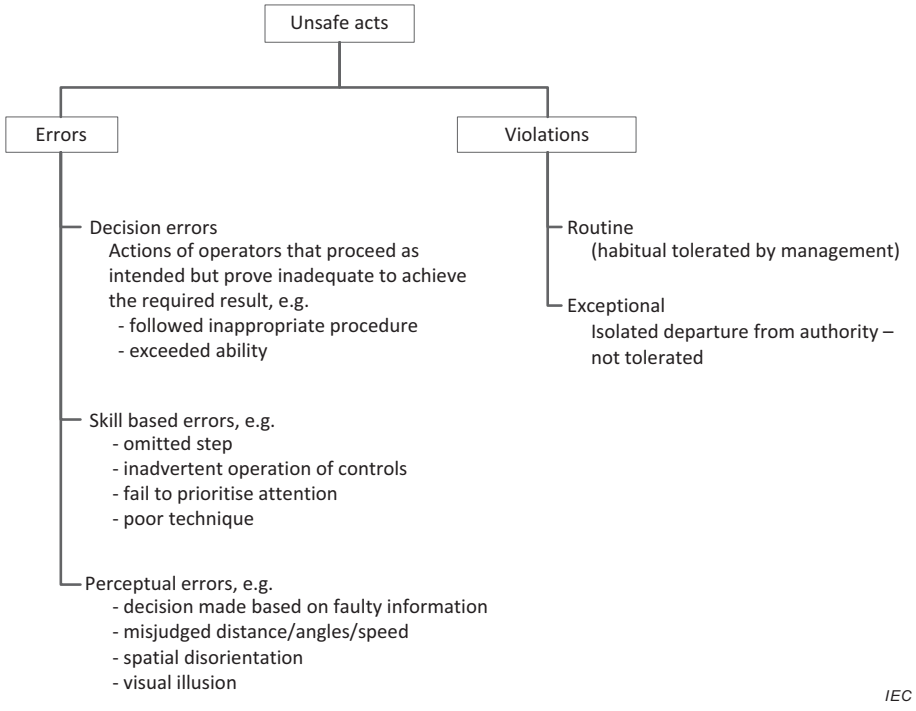

Figure E.3 – Level 1: Unsafe acts

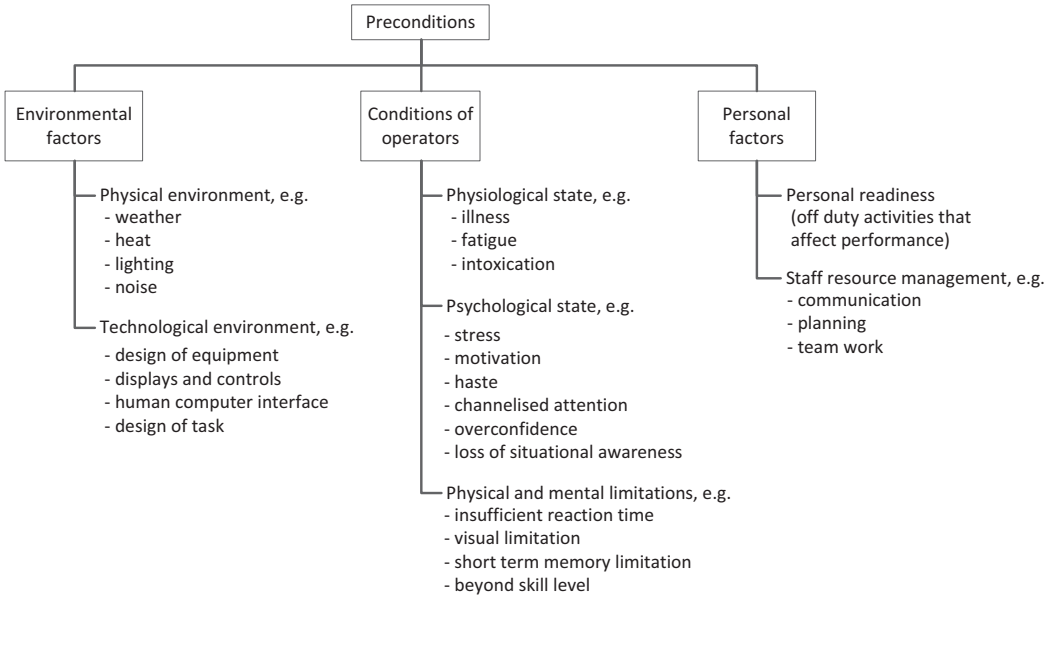

Figure E.4 – Level 2: Preconditions

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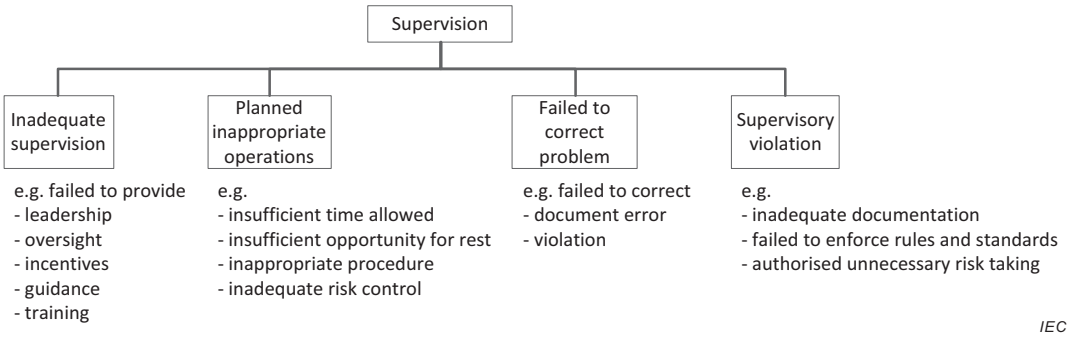

Figure E.5 – Level 3: Supervision Issues

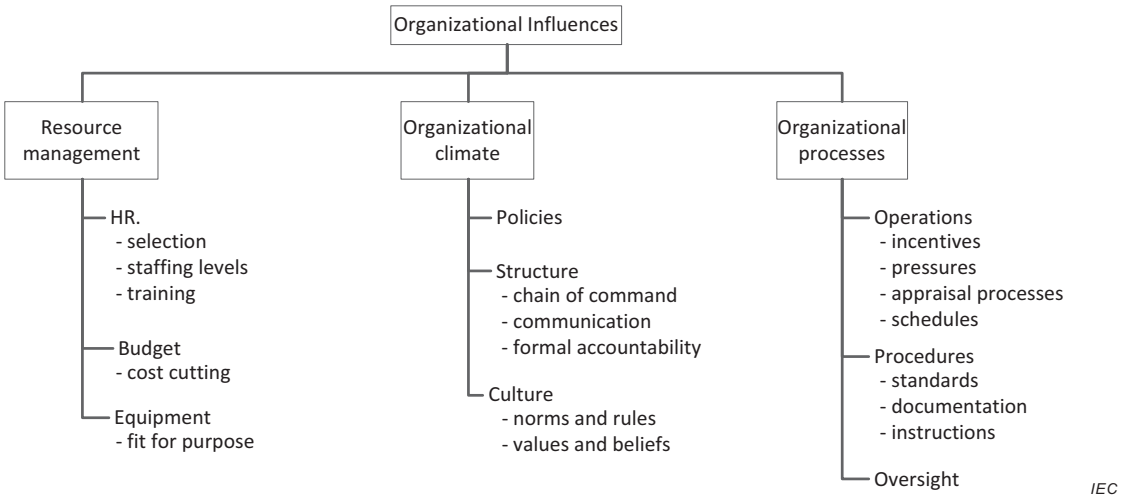

Figure E.6 – Level 4: Organizational Issues

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